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ABSTRACT

Up-to-date knowledge about Skylab experiments is presented for the purpose of informing high school teachers about scientific research performed in orbit and enabling them to broaden their scope of material selection. The second volume emphasizes the sensing of earth resources. The content includes an introduction to the concept and historical significance of remote sensing, a discussion of major scientific considerations involved in remotely sensing the earth, and descriptions of experiments with multispectral photographic facility, infrared spectrometers, multispectral scanners, microwave scatterometers and altimeters, and L-band radiometers. Experiment background, scientific objectives, application of equipment, and data output are explained in each description. Related curriculum activities, suggested classroom demonstrations, and an outline for the relationships between experimental data and instructional materials are presented. Included in the appendices are additional remote sensor information, a glossary of terms used in this volume, and a selected bibliography. (CC)

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Skylab Experiments

Volume 2
Remote Sensing of Earth Resources

Produced by the Skylab Program and NASA's Education Programs Division in Cooperation with the University of Colorado

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546, May 1973

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PREFACE

The most immediate benefits that derive from a multidisciplined scientific program such as Skylab are a large volume and wide range of scientific information. A secondary benefit is that this very large amount of up-to-date information can be related in a timely manner to high school curricula. The time lag between the generation of new information and its appearance in text books is often measured in years rather than in months.

It is the intent of the Skylab Education Program to eliminate this characteristically long delay by timely presentation of scientific information generated by the Skylab program. The objective is not to teach Skylab to the schools, but rather to use Skylab science as a focus for science education in the high schools. Readers are urged to use the descriptions of investigations and scientific principles, and the demonstration concepts contained herein as stimuli in identifying potential educational benefits that the Skylab program can provide.

National Aeronautics and Space Administration
Washington, D.C. 20546
May 1973

CONTENTS

TITLE	*PAGE*
PREFACE	i
INTRODUCTION	iv
THE SKYLAB EDUCATION PROGRAM	iv
APPLICATION	iv
ACKNOWLEDGMENTS	v
THE SKYLAB PROGRAM	vii
THE SKYLAB SPACECRAFT	vii
THE SKYLAB EARTH RESOURCES EXPERIMENT PROGRAM	ix
Scheduling	xi
Data Return	xi
SECTION 1—INTRODUCTION TO THE REMOTE SENSING OF EARTH RESOURCES	
BACKGROUND	1
Skylab Earth Resource Investigations	3
SCIENTIFIC CONSIDERATIONS	4
Electromagnetic Radiation	4
Atmospheric Effects	8
Resolution	11
Information Available from Remote Sensing	11
SECTION 2—MULTISPECTRAL PHOTOGRAPHIC FACILITY (S190)	
BACKGROUND	21
SCIENTIFIC OBJECTIVES	21
Multispectral Photographic Camera (S190A)	21
Earth Terrain Camera (S190B)	22
EQUIPMENT	22
Multispectral Photographic Camera (S190A)	22
Earth Terrain Camera (S190B)	25
PERFORMANCE	27
Crew Activities	27
Constraints	27
DATA OUTPUT	27
SECTION 3—INFRARED SPECTROMETER (S191)	
BACKGROUND	29
SCIENTIFIC OBJECTIVES	31
EQUIPMENT	32
PERFORMANCE	37
Crew Activities	37
Constraints	37
DATA OUTPUT	37
SECTION 4—MULTISPECTRAL SCANNER (S192)	
BACKGROUND	39
SCIENTIFIC OBJECTIVES	39
EQUIPMENT	40
PERFORMANCE	42
Crew Activities	42
Constraints	42
DATA OUTPUT	42

SECTION 5—MICROWAVE RADIOMETER/SCATTEROMETER AND ALTIMETER (S193)
BACKGROUND 45
SCIENTIFIC OBJECTIVES 47
EQUIPMENT 47
DATA OUTPUT 48

SECTION 6—L-BAND MICROWAVE RADIOMETER (S194)
BACKGROUND 57
SCIENTIFIC OBJECTIVES 57
EQUIPMENT 57
PERFORMANCE 58
Crew Activities 58
Constraints 58
DATA OUTPUT 58

SECTION 7—RELATED CURRICULUM ACTIVITIES
RELATED CURRICULUM TOPICS 61
SUGGESTED CLASSROOM DEMONSTRATIONS 64

SECTION 8—APPENDICES
APPENDIX A—REMOTE SENSOR DISCUSSION
GENERAL 71
CAMERAS 71
Multispectral Cameras 72
RADIOMETERS 72
Microwave Radiometer 72
SCANNERS 73
Infrared Scanner 73
SPECTROMETERS 74
Infrared Spectrometer 74
RADARS 75
Scatterometer 75
APPENDIX B—GLOSSARY 77
APPENDIX C—SELECTED BIBLIOGRAPHY 83

INTRODUCTION

The Skylab Education Program

This year the United States' first manned scientific space station, Skylab, will be launched into orbit and will be the facility in which successive crews of astronauts will perform investigations in a number of scientific and technological disciplines. The program of investigations can be divided into four broad categories: physical sciences, biomedical sciences, Earth applications, and space applications.

The Skylab scientific program will produce information that will increase our understanding of science and will extend our knowledge of subjects ranging from the nature of the universe to the structure of the single human cell. It is one of the objectives of the National Aeronautics and Space Administration that the knowledge derived from its programs be made available to the educational community for application to school curricula in a timely manner.

For this reason, the Skylab Education Program was created to derive the maximum educational benefits from Skylab, assist in documentation of Skylab activities, and enhance the understanding of scientific developments.

This document is one of several volumes prepared as a part of the education program. It has the dual purpose of informing high school teachers about the scientific investigations performed in orbit, and enabling teachers to form an opinion of the educational benefits the program can provide.

In providing information on the Skylab program, these books will define the objectives of each scientific investigation and describe its scientific background. The descriptions will include discussions of the scientific principles applied in the investigations and the types of data generated, and the types of related information and data available from other sources in the Skylab program.

In the preparation of these descriptions of the Skylab activities, a continuing goal has been to build a bridge between Skylab science and high school science. Discussions of the scientific background behind the Skylab investigations have been included to illustrate the scientific needs for performing those investigations in the Skylab environment. Wherever possible, concepts for classroom activities have been included that use specific elements of Skylab science as focal points for the increased understanding of selected subjects in the high school curricula. In some areas, these endorse current curriculum topics by providing practical applications of relatively familiar, but sometimes abstract, principles. In other areas, the goal is to provide an introduction to phenomena rarely addressed in high school curricula.

It is a goal of the Skylab Education Program that these volumes will stimulate the high school teacher to the recognition that scientific programs such as Skylab produce information and data that neither are, nor were planned to be, the exclusive domain of a small group of scientists, but rather that these findings are available to all who desire to use them.

Application

Readers are urged to evaluate the investigations described herein, in terms of the subjects they teach and the text books and classroom aids they use. Teachers will be able to apply

the related curriculum topics as stimuli for application of Skylab program-generated information to classroom activities. This information can be in the form of film strips, voice tapes, experiment data, etc. and can be provided to fulfill teachers' expressed needs. For example, the teacher may suggest educational aids that can be made available from these information sources, which would be useful in classroom situations to illustrate many of the principles discussed in high school curricula. These suggestions could then serve as stimuli for development of such aids.

As information becomes available, periodical announcements will be distributed to teachers on the NASA Educational Programs Division mailing list. Teachers wishing to receive these announcements should send name, title, and full school mailing address (including zip code) to:

National Aeronautics and Space Administration
Washington, D.C. 20546
Mail Code FE

This volume covers the broad area of earth resources in which Skylab experiments will be performed. Included is a brief description of the Skylab Program, its objectives and vehicles.

Section 1 introduces the concept and historical significance of remote sensing, and discusses the major scientific considerations involved in remotely sensing the earth's resources, particularly as applicable to sensing from spacecraft. Following this discussion, sections 2 through 6 provide a description of the individual Earth Resource sensors and experiments to be performed on Skylab. Each description includes a discussion of the experiment background and scientific objectives, the equipment involved and a discussion of significant experiment performance areas.

Section 7 — Related Curriculum Activities, includes an outline of the areas of science curriculum to which experimental data, or information concerning the scientific principles, can be related (refer to Table 1 for a summary matrix of related curriculum topics). This section also includes a sample of suggested classroom activities which may be of interest to some readers.

Section 8 includes the following appendices: Appendix A, providing additional remote sensor information; Appendix B, which contains a glossary of terms used in this volume; and Appendix C, a selected bibliography.

Acknowledgements

Valuable guidance was provided in the area of relevance to high school curricula by Dr. James R. Wailes, Professor of Science Education, School of Education, University of Colorado; assisted by Mr. Kenneth C. Jacknicke, Research Associate on leave from the University of Alberta, Edmonton, Alberta, Canada; Mr. Russell Yeany, Jr., Research Associate, on leave from the Armstrong School District, Pennsylvania; and Dr. Harry Herzer and Mr. Duane Houston, Education and Research Foundation, Oklahoma State University.

Subject / Experiment	Biology	Chemistry	Earth Science	Electronics	Mathematics	Photography	Physics	Social Science
Section 1 Introduction to Remote Sensing of Earth Resources	Migration habits	Relation between energy absorbed & chemical nature	Remote sensing Spectral signatures Cartography		Scale computation	Infrared Imaging	Electromagnetic radiation Absorption Scattering	Habitation concentration Natural political boundaries
Section 2 S190 Multispectral Photographic Facility		Absorption Spectrum of chemicals Spectral analysis	Topographical mapping Agricultural stresses Pollution Population Land Use		Scales	Film emulsions Multispectral Lenses Filters	Optics, Energy Lens resolution Light theory Wavelength & source Electromagnetic spectrum, Reflection Refraction	
Section 3 S191 Infrared Spectrometer		Visible and Infrared detectors	Atmosphere Radiation	Remote sensors Detectors Calibration Spectrometer	Units	Filters Cameras Cassegrain optics	Optics, Energy Spectrometry Black Body Dichroic Prism	
Section 4 S192 Multispectral Scanner	Absorption characteristics of chlorophyll	Absorption characteristics of chlorophyll	Climatology Agriculture Forestry, Land use Geology, Oceans Atmosphere	Optical scanners Detectors Data collection	Trig Units Geometry		Spectrum Optics Heat Reflecting telescope Dichroic Prism	
Section 5 S193 Microwave Radiometer/ Scatterometer And Altimeter	Distribution of biomes		Agriculture, Oceans Atmosphere Sea states Biomes Climatology	Radar Microwave Radiometer Scatterometer Altimeter	Trig Units Geometry		Light Spectrum Back-scattering Dielectrics Black Body	
Section 6 S194 L-Band Microwave Radiometer	Pollution effects	Effect of pollutants Relation between microwave reflection & dielectric constant	Radiation Sea States Brightness Temp Atmosphere Faults	Sensors Radiometer			Light Spectrum Heat Black Body	
Section 7 Appendix A— Remote Sensor Discussion				Radiometers Antennas Scanners Spectrometry Radar		Cameras Films Filters	Electromagnetic radiation Cryogenics Spectrometry	

Table 1 Related Curriculum Topics

The Skylab Program

The Skylab orbiting space station will serve as a workshop and living quarters for the astronauts as they perform investigations in the following broad categories: physical sciences, biomedical sciences, Earth applications, and space applications.

During the eight-month operational lifetime of Skylab, three crews, each consisting of three men, will live and work in orbit for periods of up to one month, two months, and two months, respectively.

The objectives for each of the categories of investigation are summarized as follows.

Physical Science—To perform observations away from the filtering and obscuring effects of the Earth's atmosphere in order to increase man's knowledge of the Sun and of its importance to Earth and mankind, to provide information in the field of stellar and galactic astronomy, and to increase man's knowledge of the radiation and particle environment in near-Earth space and of the sources from which these phenomena emanate.

Biomedical Science—To make observations under conditions different from those on Earth and thereby increase man's knowledge of the biological functions of living organisms, and of the capabilities of man to live and work for prolonged periods in the orbital environment.

Earth Applications—To develop techniques for observing from space and interpreting Earth phenomena in the areas of agriculture, forestry, geology, geography, oceanography, air and water pollution, land use and meteorology, and the influence man has on these elements.

Space Applications—To develop techniques for operation in space in the areas of crew habitability and mobility, and use the properties of weightlessness in materials research.

The Skylab Spacecraft

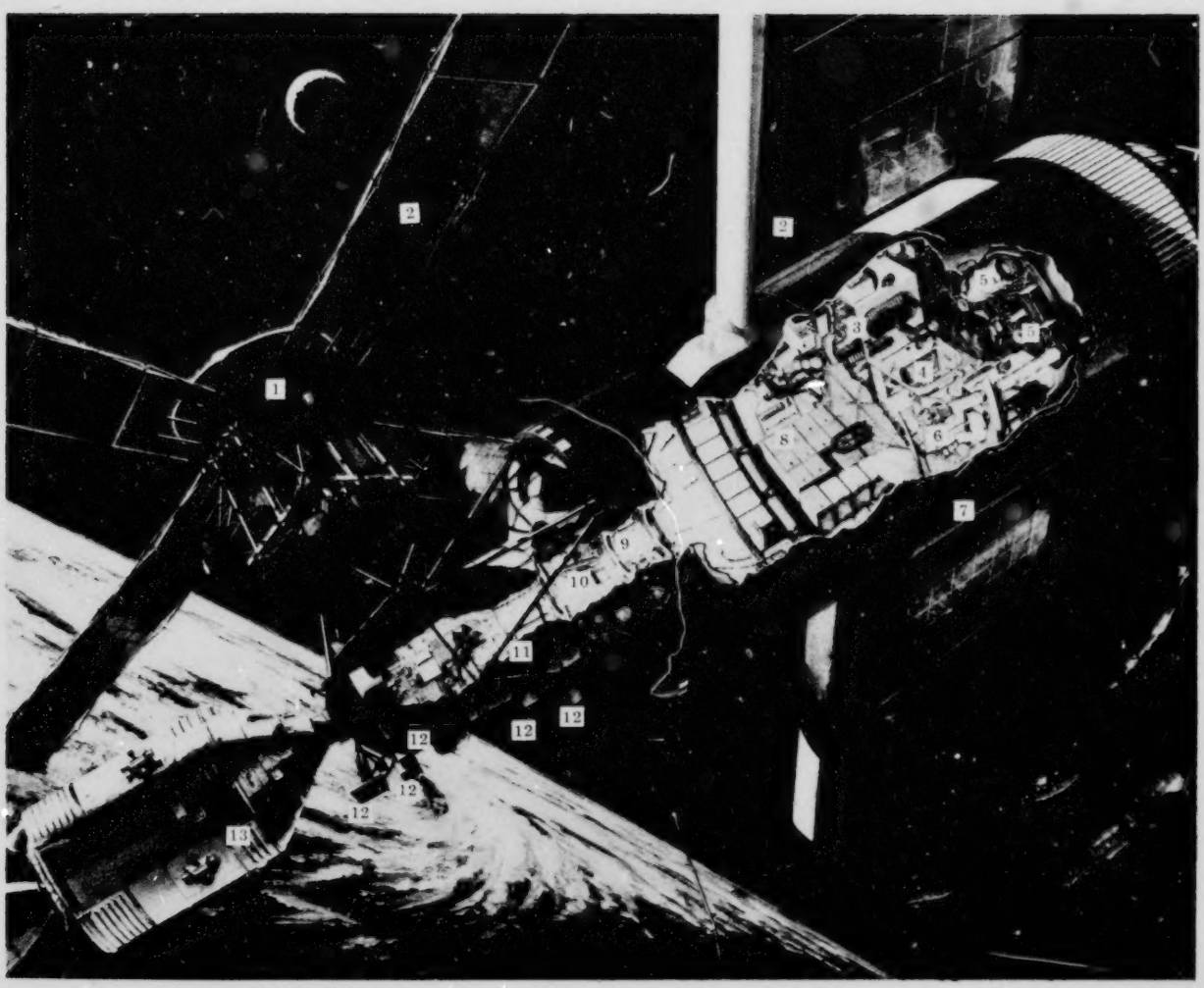
The five modules of the Skylab cluster are shown in the illustration.

The orbital workshop is the prime living and working quarters for the Skylab crews. It contains living and sleeping quarters, provision for food preparation and eating, and personal hygiene equipment. It also contains the equipment for the biomedical science experiments and for many of the physical science and space applications experiments. Solar arrays for generation of electrical power are mounted outside this module.

The airlock module is the prime area in which control of the cluster internal environment, and workshop electrical power and communications systems, is located. It also contains the airlock through which suited astronauts emerge to perform their activities outside the cluster.

The multiple docking adapter provides the docking port for the command/service modules that transport the crews, and contains the control center for the telescope mount experiments and systems. It also houses the Earth applications experiments and space technology experiments.

The Apollo telescope mount houses a sophisticated solar observatory having eight telescopes observing varying wavelengths from visible, through near and far ultraviolet, to x-ray. It contains the gyroscopes and computer of the primary system by which the flight attitude of



1	Apollo telescope mount	7	Orbital workshop
2	Solar arrays	8	Experiment compartment
3	Sleeping quarters	9	Airlock module
4	Personal hygiene	10	Airlock external hatch
5	Biomedical science experiment	11	Multiple docking adapter
6	Ward room	12	Earth resources experiments
		13	Command and service module

Skylab Orbiting Station

Skylab is maintained or changed, and it carries solar arrays by which about half of the electrical power used by the cluster is generated.

The command and service module is the vehicle in which the crew travels from Earth to Skylab and back to Earth, and in which supplies are conveyed to Skylab and experiment specimens and film are brought to Earth.

Skylab will fly in a circular orbit about 436 kilometers (235 nautical miles) above the surface of Earth, and is planned to pass over any given point within latitudes 50° north and 50° south of the equator every five days. In its orbital configuration, Skylab will weigh over 44,100 kilograms (200,000 pounds) and will contain nearly 370 cubic meters (13,000 cubic feet) for work and living space (about the size of a three-bedroom house).

THE SKYLAB EARTH RESOURCES EXPERIMENT PROGRAM

The Earth Resources Experiment Program (EREP) on Skylab contains sensors operating in selected frequency bands throughout the visible spectrum and into the microwave range. The equipment used includes:

- The Multispectral Photographic camera (S190A) consisting of a group of six cameras all carefully aligned on a common target point on the earth's surface, and an Earth Terrain Camera (S190B) having larger focal length than the six multispectral cameras and therefore greater resolving power.

- The Infrared Spectrometer (S191) designed to perform spectral radiance measurements in the visible through near-infrared ranges, as well as in the thermal infrared spectral band, on specific ground areas selected by the crew.

- The Multispectral Scanner (S192) which operates in thirteen discrete spectral bands (including the visible and infrared) to obtain spectral signature information for agriculture, forestry, geology, hydrology, and oceanography analysis.

- The Microwave Radiometer/Scatterometer and Altimeter (S193) which operates in the microwave range and will obtain active radar back-scattering, passive microwave emission measurements, and pulse shape altimeter measurements.

- And, the L-Band Radiometer (S194) which measures the brightness temperature of the earth's surface in the microwave region, but operates at a different wavelength than the S193 radiometer.

Figure 1 illustrates the principal functional inter-relationships between the various Skylab earth sensors, and shows the relationship of the spacecraft data to supporting data (i.e., ground data, aircraft data, ship/buoy data, and other spacecraft data).

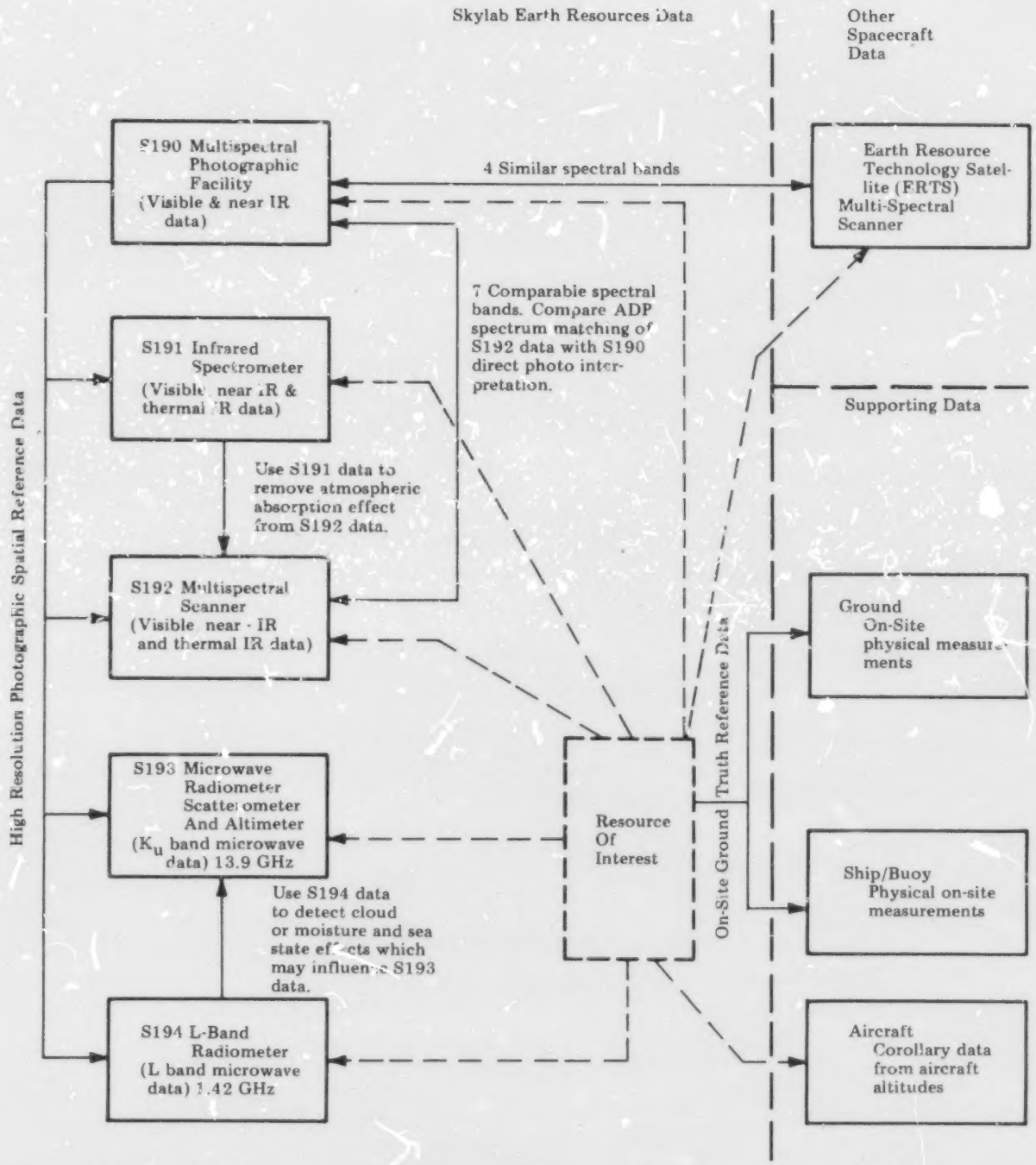

Skylab Earth Resources Data
Other Spacecraft Data
S190 Multispectral Photographic Facility (Visible & near IR data)
4 Similar spectral bands
Earth Resource Technology Satellite (ERTS) Multi-Spectral Scanner
7 Comparable spectral bands. Compare ADP spectrum matching of S192 data with S190 direct photo interpretation.
S191 Infrared Spectrometer (Visible near IR & thermal IR data)
Supporting Data
Use S191 data to remove atmospheric absorption effect from S192 data.
S192 Multispectral Scanner (Visible near - IR and thermal IR data)
Ground On-Site physical measurements
High Resolution Photographic Spatial Reference Data
Truth Reference Data
On-Site Ground
Resource Of Interest
S193 Microwave Radiometer Scatterometer And Altimeter (K_u band microwave data) 13.9 GHz
Ship/Buoy Physical on-site measurements
Use S194 data to detect cloud or moisture and sea state effects which may influence S193 data.
S194 L-Band Radiometer (L band microwave data) 1.42 GHz
Aircraft Corollary data from aircraft altitudes

Figure 1 Skylab Earth Resource Experiment Inter Relationship

SCHEDULING OF SKYLAB EARTH RESOURCES EXPERIMENTS

During the Skylab mission, areas of the earth surface will be remotely sensed that are of particular interest to earth resource investigators. In order to perform earth resource data passes, it is necessary to re-orient the Skylab orbital assembly from its normal attitude wherein the solar arrays and the solar telescope point directly at the sun, to an orbital mode which provides continuous pointing of the cameras and other earth resource sensors at the ground directly below the spacecraft. A total of 60 such passes are now planned, and 5 passes with Skylab in its normal solar oriented attitude are assigned for earth observation activities. The following table illustrates the apportionment of these passes by Skylab mission:

Skylab Mission	*Number of Earth Pointing Passes*	*Number of Solar Oriented Passes*
SL-2	14	1
SL-3	26	2
SL-4	20	2
TOTAL	60	5

DATA RETURN

The Skylab earth resource sensors may be operated singly or in various combinations depending on the scientific requirements, or other factors such as weather and vehicle capability limitations. In any event, the data will be recorded on magnetic tape and film and returned to the NASA Johnson Space Center for initial processing. From the three Skylab missions, a total of 10,400 frames of color and 29,800 frames of black and white 70 millimeter film are planned to be returned to earth from S190A; 7,200 frames of color and black and white film will be returned from S190B; and approximately 50,400 frames of 16 millimeter black and white film will be returned from the S191 data acquisition camera. Digital data will consist of a total of 25 reels of magnetic tape.

Data acquired from the Earth Resource experiments conducted on the Skylab missions will be available to the general public when cataloged and received at the Department of Interior's, Earth Resource Observation System (EROS) Data Center, Sioux Falls, South Dakota. Inquiries to EROS may be addressed as follows:

EROS DATA CENTER
SIOUX FALLS, S.D. 57198
Phone: (605) 339-2270

Section 1

Introduction

BACKGROUND

Remote sensing is the name given to the technique of measuring information about a subject of interest without being in direct contact with it. The technique relies on detecting electromagnetic radiation which is either reflected or emitted by the subject. When applied to the earth as seen from orbital altitudes, remote sensing has the potential of yielding information which is of fundamental importance for effective use and conservation of natural resources in both developing and technically advanced nations. The Skylab Earth Resources Experiment Package (EREP) will provide the experimental data upon which to base answers to such questions as: which wavelength to use for a particular application, how many channels of data are really required, what scale and resolution should be provided, and what area of the earth's surface should be covered at one time? While these answers are needed to design the operational systems of the future, the data gathered during the Skylab mission also have immediate applications to earth resource management and education. However, in order to more clearly understand the earth resources experiment discussions which follow in this volume, it is necessary to first familiarize ourselves with the concepts of remote sensing.

ELECTROMAGENTIC RADIATION— Energy transmitted through space or through a material medium in the form of electromagnetic waves. The term can also refer to the emission and propagation of such energy. Whenever an electric charge oscillates or is accelerated, a disturbance characterized by the existence of electric and magnetic fields propagates outward from it. This disturbance is called an electromagnetic wave. The frequency range of such waves is tremendous and is known as the ELECTROMAGNETIC SPECTRUM. All electromagnetic waves travel with the velocity of light.

Remote sensing is not new to mankind. Four of man's five senses are remote sensors, acquiring data concerning an object from a distance. The olfactory senses react with molecules given off by an object, thus providing odor detection. The ear detects pressure pulses. The skin has pressure and temperature sensors that do not require contact, and the eyes are sensitive to electromagnetic radiation in the 0.4 to 0.7 micrometer region (the visible spectrum).

To improve upon his "data gathering" techniques there are two things man can do:

— Better utilize his sensing devices (i.e., go to the top of a hill for a better view)

— Or, develop instruments with greater sensitivity than his own fairly limited senses.

Aerial photography is an example of the combination of both these two improvements.

Photography from orbital altitudes in the visible and near-infrared spectral regions has already proven to be an invaluable complement to survey from aircraft and from ground level for standard synoptic mapping of geographic features over large areas. The use of multispectral remote sensing techniques over an extensive wavelength region has the potential of greatly extending the scope of this capability to include mapping of terrestrial resources and land uses on a

global scale. For example, resources amenable to study are: crop and forestry cover; health state of vegetation; types of soil; water storage in snow pack; surface or near surface mineral deposits; sea surface temperature; and the location of likely feeding areas for fish. Comprehensive surveys of such resources will help cope with developing world-wide problems of such accelerating urgency as food supplies, mineral shortages, energy needs, environment pollution and expanding patterns of human settlements.

Until the advent of color films, the images recorded by cameras were produced in varying tones of a single color, with black or shades of gray being the most common. The development of color film and of lenses of high quality enables photographers to produce images of great realism, and also enabled the camera to become a high precision scientific instrument.

Since development of the camera, photography using the visible portion of the spectrum has been applied to a steadily increasing variety of tasks. At the close of World War II, the use of aerial photography suddenly accelerated in quantity and scope. In addition to its classic military uses, it has been found virtually indispensable in political, economic, and scientific applications. Extensive application in the immediate future is indicated in geological surveys; soils mapping; wildlife, range and watershed management; agriculture; urban analysis and planning; archaeology; and geography.

None the less, many of the photography techniques of aircraft remain relatively modest extensions of the capabilities of the human eye. Numerous methods of analysis and inference have been developed and the use of high-speed aircraft has become common, yet the range of usefulness for aerial photography remains more restricted than is desirable. The principal restriction of such systems is the cost of performing surveys over large areas, particularly when it is important that the survey be performed all at the same time, or under uniform lighting conditions.

Perhaps the most important gain that surveys from orbital altitudes can provide is the capability to observe massive areas of the earth with a frequency that will allow study of phenomena that vary significantly with time. These include crop development and water drainage, for example.

Satellites have been used since early in the beginning of the space program to provide meteorological data for better weather forecasting and timely warning against life threatening atmospheric disturbances. Examples are the Nimbus, Tiros and ATS satellites equipped with visible and infrared sensors. The first unmanned satellite designed to expand earth resources surveys was launched in 1972. It is designated

ERTS-1 (Earth Resources Technology Satellite). Operating at an orbital altitude of 912 kilometers (492 nautical miles), the ERTS-1 spacecraft carries two types of imaging sensors: the return beam vidicon cameras and the multispectral scanner, and is capable mapping 161 million square kilometers of the earth per week (10,000 photographic images/week). A malfunction in a power switching circuit curtailed the operation of the return beam vidicon cameras early in the mission. The multispectral scanner, on the other hand, has been operating satisfactorily since launch, acquiring an average of 188 scenes per day in each of four spectral bands, two in the visible and two in the near infrared (IR). The imagery obtained thus far from the multispectral scanner has exceeded pre-mission expectations with regard to spatial and spectral quality and indicate that ERTS has an excellent capability to supply timely information of changing and dynamic scenes at 18 day intervals. This timely information is of particular significance to users and investigators concerned with monitoring agricultural, forestland/rangeland, land use, water, snow cover and coastal marine resources at scheduled intervals.

Development and testing of techniques for remote sensing and for interpretation of the instrument response over a given site and correlation with the field measured characteristics of that target (ground test sites) are part of NASA's earth resources program. Aircraft conduct aerial reconnaissance of ground test sites from altitudes ranging up to 18,290 meters (60,000 feet) to test measuring equipment, validate interpretive techniques and ascertain the dependability of recognizable spectral signatures. Development has reached the point where remote sensing techniques have been used operationally to assist, for example, in such problems as pinpointing forest fires through dense smoke cover and clouds, mapping corn blight damage, and elm tree disease detection and mapping (Dutch Elm Disease).

Some exploratory tests of remote sensing techniques have also been conducted from manned spacecraft during Gemini and Apollo missions. Several thousand earth pictures of high quality obtained by the Gemini crews have been widely distributed to potential users and effectively used in many disciplines. Apollo provided the opportunity for utilizing these photographic techniques over and beyond those employed in Gemini. Significant Apollo advances involved the addition of haze filters, multiband photography in the visible and near-infrared wavelength regions; overlap photography for stereo viewing; and photography of ground test sites.

Skylab Earth Resource Investigations

The Skylab Earth Resource Experiment Package (EREP) design and operation has been planned for a wide variety of

scientific uses. NASA extended an invitation to potential domestic and foreign investigators in December 1970 to submit proposals for the analysis and application of earth resource scientific data to their particular areas of interest. Based on the proposals received, NASA has selected Principal Investigators to direct 148 investigations.

The following table 2 shows the distribution, by major discipline and sub-discipline, of the experiment tasks proposed by these Principal Investigators. Note that some experiments encompass multi-discipline tasks, therefore the total number of tasks exceed the total number of investigations.

SCIENTIFIC CONSIDERATIONS

Electromagnetic Radiation

Each individual feature of the earth's surface emits, or reflects, radiation of different frequencies in different ways; consequently, observation in these spectral ranges, either singly or simultaneously, can provide a wide variety of information.

The total electromagnetic spectrum extends from the extremely short wavelength cosmic rays to the extremely long wavelength of the earth's natural resonance. Figure 2 illustrates the electromagnetic spectrum range, and emphasizes that portion that is most familiar to the high school student.

Different surface features reflect different wavelengths with different intensities as illustrated in Figure 4. This figure shows that the intensity of reflected light from a packed sandy road has a radiance in the 0.6 micrometer frequency range seven times that of soy beans; while in the 0.9 micrometer range soy beans have a radiance more than twice that of the sandy road. The variation in reflectance or emission in different spectral frequencies is called the spectral signature of the material.

SPECTRAL SIGNATURE— refer to Glossary for definition.

When the surveys are extended to the infrared and longer microwave bands, the emitted radiation is significant. In this case, the energy sensed is solar energy which has been absorbed and then reradiated. Figure 3 illustrates the spectral image variations detectable in six selected spectral bands taken simultaneously of the same scene from an aircraft. The three photos on the left are in the visible spectrum (with peaks in the violet, yellow-orange and red colors, respectively), while the three photos on the right are in the near-IR and intermediate-IR parts of the electromagnetic spectrum.

SPECTRAL— The distribution of electromagnetic radiation as a function of wavelength. In the visible range, variations are noted by changes in color.

Table 2 Skylab EREP Experiment Tasks

Discipline/Sub-Discipline	*Number of Tasks Proposed*
Agriculture/Range/Forestry	
Crop Inventory	9
Insect Infestation	2
Soil Type	4
Soil Moisture	4
Range Inventory	1
Forest Inventory	3
Forest Insect Damage	2
Geological Applications	
Mapping	12
Metals Exploration	9
Hydro Carbon Exploration	2
Rock Types	4
* Volcanos	6
Earth Movements	4
Continental Water Resources	
Ground Water	3
Snow Mapping	2
Drainage Basins	7
Water Quality	4
Ocean Investigations	
Sea State	5
Sea/Lake Ice	2
Currents	3
Temperature	1
Geodesy	1
Living Marine Resources	5
Atmospheric Investigations	
Storms, Fronts, and Clouds	6
** Radiant Energy Balance	4
Air Quality	0
Atmospheric Effects	3
Coastal Zones, Shoals, and Bays	
Circulation and Pollution in Bays	3
Underwater Topography and Sedimentation	3
Bathymetry	1
Coastal Circulation	3
Wetlands Ecology	2
Remote Sensing Techniques Development	
Pattern Recognition	2
Microwave Signatures	3
Data Processing	1
Sensor Performance Evaluation	5
Regional Planning and Development	
Land Use Classification Techniques	9
Environmental Impacts — Special Topics	5
State and Foreign Resources	9
Urban Applications	4
Coastal/Plains Applications	2
Mountain/Desert Applications	2
Cartography	
Photomapping	4
Map Revision	1
Map Accuracy	4
Thematic Mapping	1
TOTAL	172

* Skylab Student Experiment Number ED-12, "Space Observation and Prediction of Volcanic Eruptions" is also investigating terrestial volcanic activity.

** Skylab Student Experiment Number ED-11, "Earth's Absorption of Radiant Heat" is investigating the atmospheric attenuation of radiant energy.

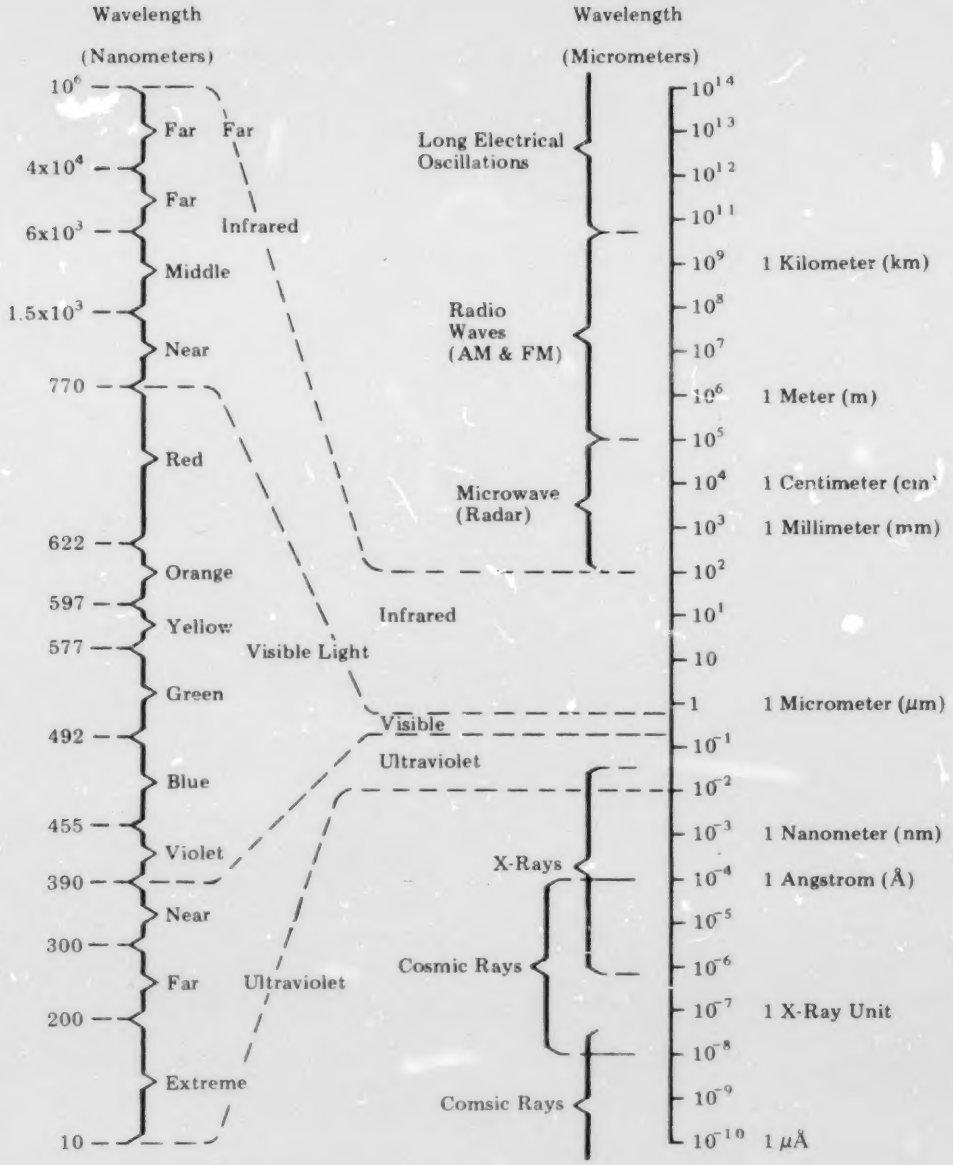
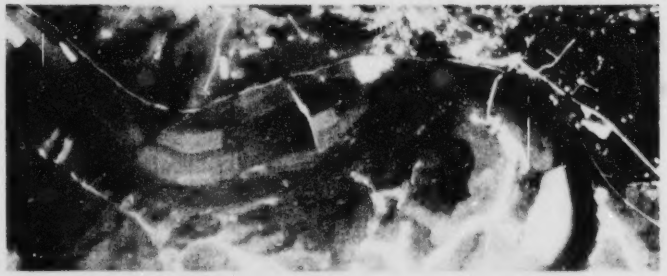
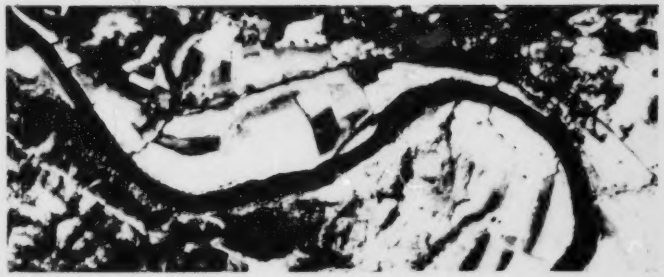


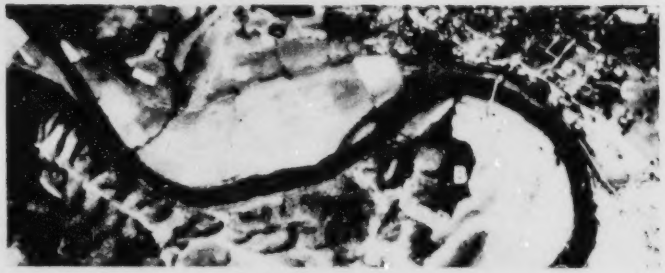
Figure 2 Electromagnetic Spectrum



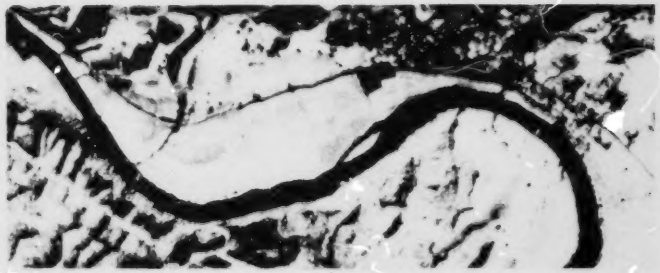
0.40 to 0.44 μm



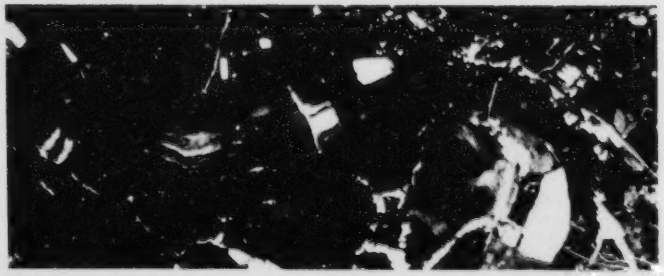
0.80 to 1.00 μm



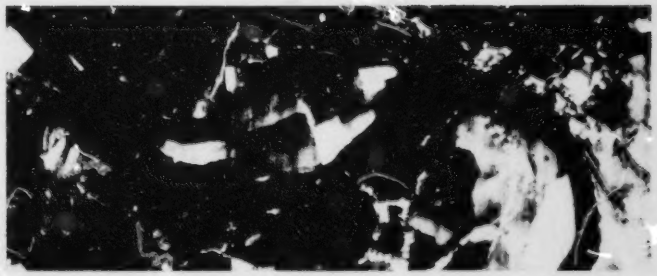
0.58 to 0.62 μm



1.00 to 1.40 μm



0.66 to 0.72 μm



2.00 to 2.60 μm

Figure 3 Illustration of Multispectral Photographic Responses of a Scene in Six Selected Spectral Bands

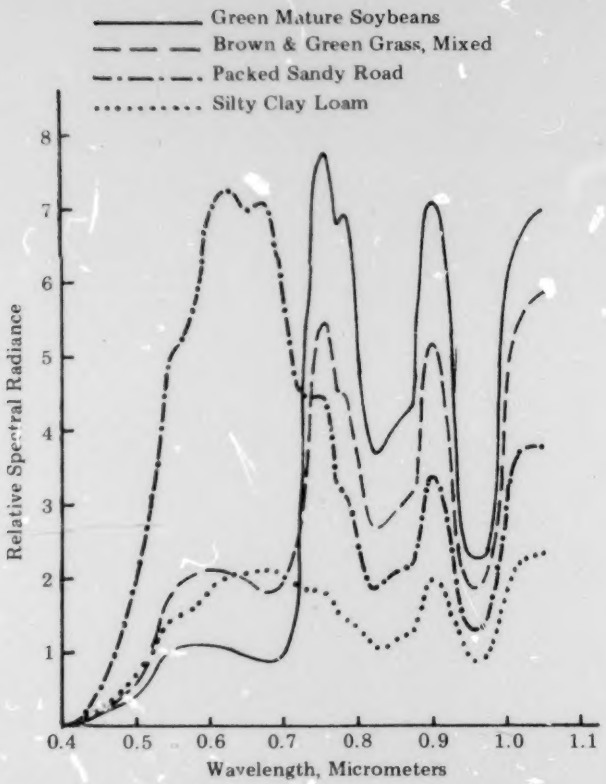


Figure 4 Illustration of Typical Spectral Signatures for Several Materials

Atmospheric Effects

Distributed along the electromagnetic spectrum are zones where the atmosphere is transparent to electromagnetic radiation, and zones where absorption by atmospheric gases cause high transmission losses making the atmosphere nearly opaque. Several of the more opaque areas and the gases causing them are shown in Figure 5. Absorption at a particular wavelength occurs where the electromagnetic energy at that wavelength is vibrating in resonance with the atoms and molecules of the atmospheric gases. Typically, in the ultraviolet region, the absorption is mainly due to atmospheric ozone; in the infrared, mainly due to carbon dioxide and water vapor; and in the microwave region, mainly due to oxygen and water vapor.

Scattering of electromagnetic energy is caused by aerosols and particles suspended in the atmosphere. Some scattering particles are dust, haze, smog, fog, or rain. The areas where scattering is important are also shown in Figure 5. Light is either absorbed by the particle and then emitted in all directions (true scattering), or is simply reflected by the

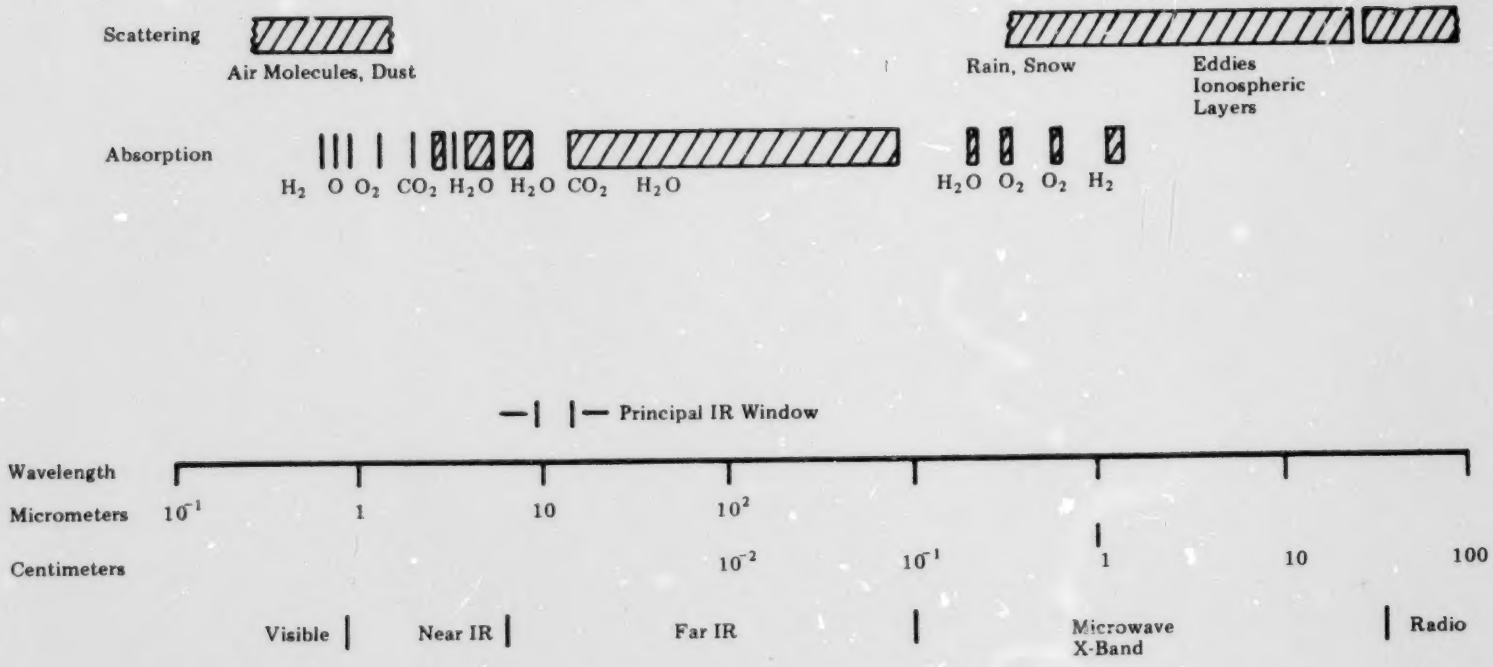


Figure 5 The Principal Atmospheric Effects As Related to the Electromagnetic Spectrum

surface of the particle. Scattering diverts some of the light from the scene so that it does not enter the sensor collector, or diverts light that is not part of the scene being observed into the sensor collector. The result in either case is a reduction in contrast and clarity. Scattering is a serious problem in the visible portion of the spectrum where cameras are used, and it is countered by the use of polarized filters or filters that tend to pass light that has not been scattered, and to block light that has been scattered.

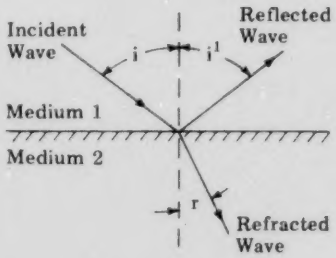
Weather is a principal cause of an opaque atmosphere. The short wavelengths of visible and infrared radiation have superior resolving properties, but they are absorbed or reflected by water vapor, fog, and clouds. Therefore, when operating in an area where weather is a problem, sensors that operate at the millimeter and centimeter wavelengths (microwaves) and can pass through fog and clouds with a minimum of attenuation must be used. As Figure 5 shows, however, even microwaves are scattered by rain and snow.

One technique to combat the weather problem is to make repeated passes over the area of interest taking data each time. As the cloud patterns change, a picture of the whole region can be pieced together from pictures of small, momentarily clear areas.

Examining the polarization of the sensed radiation can often reveal information about the texture, or chemical composition, of the reflecting surface, or of the intervening atmosphere. The natural sunlight is polarized, and the polarization is changed in varying degrees by particles in the atmosphere and by reflection from a surface. The degree to which the reflected sunlight remains polarized is useful in identifying the nature of the surface that reflected it, and the atmosphere it passed through.

POLARIZATION— A distinct orientation of the wave motion and travel of electromagnetic radiation. Discrimination techniques use differing and perhaps characteristics amounts of polarization introduced by materials in the radiation reflected or emitted to distinguish material categories.

Polarization effects and the fact that radiation in the passive microwave region originates from beneath the surface of certain terrestrial materials (e.g., ice and snow) offer promising possibilities for geologic and arctic exploration. Passive microwave signals can also provide information about the roughness or other characteristics of land or water surfaces, which would supplement data obtained from other spectral regions.



For Reflection: $i = i^1$

For Reflection: $\frac{\sin i}{\sin r} = \left[\frac{\epsilon_2}{\epsilon_1}\right]^{1/2} = N$

Where ϵ_1 and ϵ_2 are the dielectric constants of mediums 1 and 2, and N is the INDEX OF REFRACTION.

Both active and passive microwave data collection techniques have the advantage that they can be used both day and night and in the presence of cloud cover. This greatly extends their capability for obtaining continuous information concerning the earth's surface, regardless of time of day or some weather conditions. It may also supply data on meteorological conditions in areas of cloud cover that are not obtainable in other spectral regions.

Resolution

SPATIAL— The distribution of electromagnetic radiation as related to the location, shape and texture of sensed phenomena.

One of the strongest factors in sensor selection is the trade off between the minimum size of the feature to be studied and the minimum size that the sensor can record (spatial resolution). The spatial resolution requirements, in turn, depend upon the resource that is being studied. Identifying crops by planting pattern requires a sensor that can discriminate surface features of 2 to 20 meters in size.

The electromagnetic wavelength at which a sensor operates has a profound effect on the resolving power of that sensor. For crop identification it is necessary to use either a sensor such as a camera, that operates with very short wavelengths; or if weather is a problem, the only recourse may be a microwave radar in which case the commensurate coarser resolution must be accepted. Unfortunately, there are presently no practicable high resolution sensors that can penetrate weather.

However, if gross land use mapping is the area of interest, (whether an area is desert, forest, or cultivated land) the required size of feature can be as large as one hundred meters. Here, cameras would give more data than needed, so a medium resolution radiometer, or radar scatterometer, would probably be sufficient.

Some resource sciences require high spectral, rather than high spatial, resolution. For example, if an agronomist is interested in identifying crop species and health, he needs data on the reflectance of the crop in several narrow spectral bands indicating the presence or absence of chlorophyll absorption. This requires sensors that collect data simultaneously in a number of narrow spectral bands. Candidate sensors are the multispectral scanner, the multispectral camera, or a spectrometer.

Information Available From Remote Sensing

A comprehensive remote sensing system for acquisition of pictorial data over a broad spectral range includes three basic imaging techniques: photography, for the region from the near ultraviolet at 0.3 micrometers to the near-infrared at 1 micrometer; optical-mechanical scanning for the infrared region between 1 and 40 micrometers (and, for some of the work, between 0.3 and 1 micrometers); and passive microwave, or radar, for discrete regions between 1 millimeter and several centimeters, or meters, in wavelength.

Photographic imagery will yield data concerning the amount of solar energy reflected from selected objects on the earth and its cloud cover as a function of wavelength, in selected spectral regions. Electro-optical, or optical-mechanical scanning techniques are desirable to acquire digitized data over

data in the form of an electrical output, permit computer processing before final recording on photographic film or magnetic tape. Thus, the information from one spectral region may be combined additively with that from another region, for example, and a single picture produced which may represent an optimum image for certain studies. Digitizing photographic imagery data using optical scanning techniques permits computer processing of large amounts of data much more rapidly than conventional manual photo interpretation. This is particularly desirable if large quantities of images are being produced and analyzed.

Using several sensors simultaneously to detect the electromagnetic radiation signature of a scene in many different spectral bands (multispectral sensing) produces vast quantities of data. The sheer volume of the data obtained makes digital data processing techniques, using computers, desirable in order to allow data interpretation and analysis within a reasonable time interval. The 25 reels of magnetic tape resulting from the Skylab earth resource missions are capable of providing up to 30 to 40 gigabits (gigabit equals 10^9 bits) of data. A discussion of automatic data processing using computers to make logical deductions identifying resources by their spectral signatures (automatic pattern recognition) is considerably beyond the scope of this volume; however, such techniques will provide powerful tools for the use of many Skylab earth resource investigators.

Infrared and thermal imaging devices (radiometers) produce recordings of the thermal structure and behavior of the terrestrial and meteorological environment. Scientific experience has shown that terrestrial data in at least two spectral regions (e.g., 4.5 - 5.5 micrometers and 8.5 - 13.5 micrometers) are often much more useful than either one alone, therefore several infrared channels should be provided. The surface condition of the object often affects the relative emittance of the object. Since radiation emitted from the objects is being measured, the sensing system can be used day and night. Other wavelengths may be used for studies of clouds, wind, ozone distribution as it affects ultraviolet absorption, and air pollution (wavelengths corresponding to absorption regions in the atmosphere.)

EMITTANCE— The radiant emittance of a source is the power radiated per unit area of surface.

Radar imagery provides a comparative measure of the reflection from various objects on the earth or of clouds. Reflected intensity (radar back-scattering) is affected by the aspect of the terrain relative to the beam direction, by the dielectric properties and polarization (at the radar frequency) of the material, and, for elements smaller than the resolution limit, by element size. Scanning at small angles (near grazing incidence) yields intensity variations which are a function of the local slope of complex landforms; it is therefore a singularly powerful technique for topographic mapping.

DIELECTRICS— Materials which are electrical insulators. In a more general sense, dielectrics include all materials except condensed states of metals (i.e., conductors). A dielectric is a substance through which an electric attraction or repulsion (electric field) may be sustained.

Passive microwave scanning radiometers have not been developed as extensively as the other sensors discussed here as to resolution element size, but new techniques have improved thermal sensitivity and speed of operation.

The spectral frequencies in which each of the Skylab earth resource sensors (which are discussed in the following sections of this volume) operates is shown in Figure 6 together with the earth resources phenomena about which each sensor provides information. More information about various types of remote sensors can be found in Appendix A to this document.

As an illustrative example of the type of information obtainable, the following sequence of figures demonstrates the types of data produced by various remote sensors that are used for Earth Resource Surveys. It is important to note the effect of scale change between imagery taken from 912 kilometers (ERTS-1) compared to photographs taken from 6,096 meters (20,000 feet). The small scale (high altitude) photographs and imagery are useful for studying regional phenomena and relationships but often lack the resolution to do detailed studies. Large scale photographs, such as that of figure 9, permit study and identification of small features.

Figure 7 is an ERTS-1 satellite composite image of south central Colorado. The multispectral scanner aboard ERTS transmits four separate images of the same scene to earth. Each image represents the reflected energy from the scene in a limited spectral region, or band. Figure 7 is a black and white representation of a "false color" image which enhances the information available to the scientists who interpret the image. The black square indicates the coverage of the aerial photograph of Figure 8. The small arrow points to a vegetation anomaly which we will use as an orientation landmark.

(Figures 7, 8, 9, 11 and 12 furnished by the National Aeronautics and Space Administration.)

Figure 8 is black and white representation of an infrared photograph taken from 18,290 meters (60,000 feet). This scene shows the Sangre de Cristo Mountains in the upper half of the frame and the San Luis Valley in the lower half. Note how healthy, vigorous vegetation shows up dark in this photo. This is because vegetation reflects large amounts of energy in the near infrared from 0.7 to 1.0 micrometers wavelength. Although the human eye cannot see this longer wavelength light (being sensitive only to light between 0.4 and 0.7 micrometers), this special film is designed to be exposed by infrared reflectance and produce a red color upon processing. The intensity of the color is proportional to the amount of reflected infrared energy. Note how dark irrigated fields appear. The vegetation between points a-a' is of particular interest to geologists who are studying the geologic structure of the area. The vegetation grows vigorously there

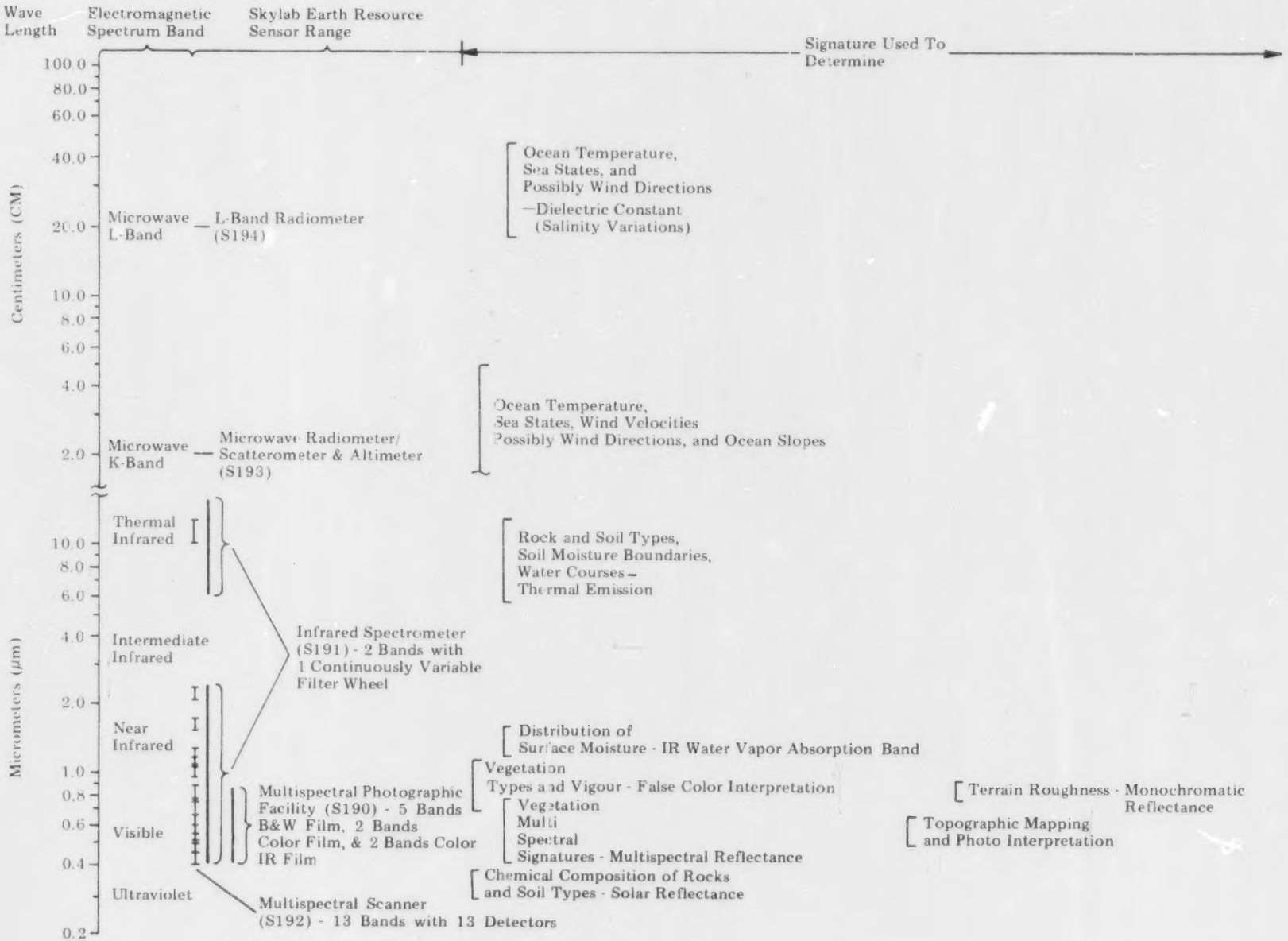


Figure 6 Skylab Earth Resource Sensor Wavelength Sensitivity Range and Application

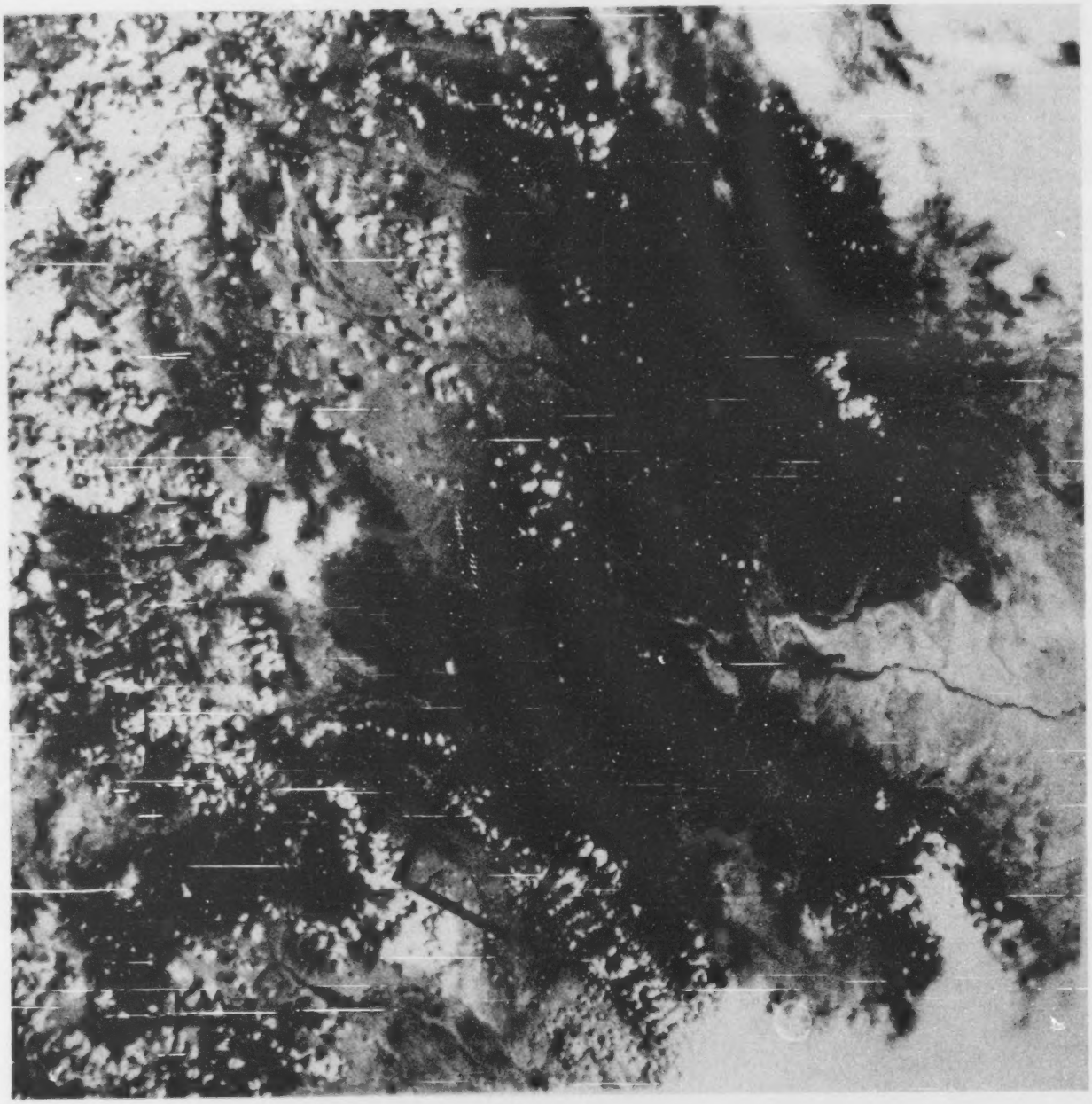
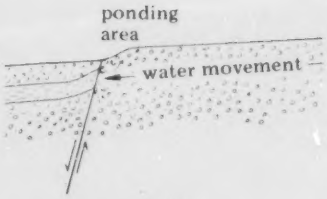


Figure 7 ERTS-1 Satellite Composite Color Image of South-Central Colorado

Figure 8 **High Altitude Color Infrared Aerial Photograph**

because a fault has impeded the subsurface flow of water from the mountains to the center of the valley. The water is forced to the surface providing for relatively vigorous vegetation growth. This same relationship can be seen on fault traces immediately to the east and west of fault trace a-a^1. The black square indicates the coverage of the aerial photograph of Figure 9. The small arrow points to a small group of trees which serve as a landmark.



Permeable alluvium

Impermeable "clay series"

Hypothetical Cross Section of a Typical Fault

Figure 9 is a large scale photograph taken from an altitude of 6,096 meters (20,000 feet). The fine resolution makes it possible to see individual trees and field rows. Fault trace a-a^1 is plainly visible and a topographical expression of the fault, known as a fault scarp, can be faintly seen extending to the southwest. Figure 10 illustrates the minor terrain variation of a fault scarp, which is marked by a dashed line on this photograph. Fault scarps are visible on other fault traces in the Figure 9 scene as well. The small arrow points to the same small group of trees.

Figure 11 is a thermal infrared scanner image obtained during the early afternoon from low altitude. The lighter tones indicate relatively warm areas. The dark areas, such as that between a-a^1, are relatively cool because of increased soil moisture and vegetation resulting in evaporative cooling. The fault scarps which extend from the areas of water impedance appear as light toned lines because they are being heated more rapidly by the sun (due to the increased slope toward the sun) than the surrounding area. The area outlined in black is the coverage of the Figure 9 photograph. It forms a trapezoid because of geometric distortions in the scanner system. The small arrow points to the small group of trees.

Figure 12 is an aerial photograph taken during early morning when the sun was only 24° above the horizon. The shadows obtained on low sun-angle photography enhance topographic features which may be related to geologic structures. The fault scarp between b-b^1 is enhanced and more easily detectable because of topographic shadowing. Other fault scarps can be seen in the same area. The small arrow points to the landmark group of trees.

A sampling and condensation of numerous scientific and technical studies in the areas of geography, agriculture, forestry, geology, hydrology, oceanography and cartography using photographic data obtained from the Gemini and Apollo missions and from aircraft is contained in an excellent monograph obtainable from the U.S. Government Printing Office, Washington, D.C. 20402, and may be of interest to some readers. The monograph is titled: "Ecological Surveys from Space," National Aeronautics and Space Administration, 1970, Monograph # SP-230. Library of Congress Card Number 76-605799. Price $1.75.

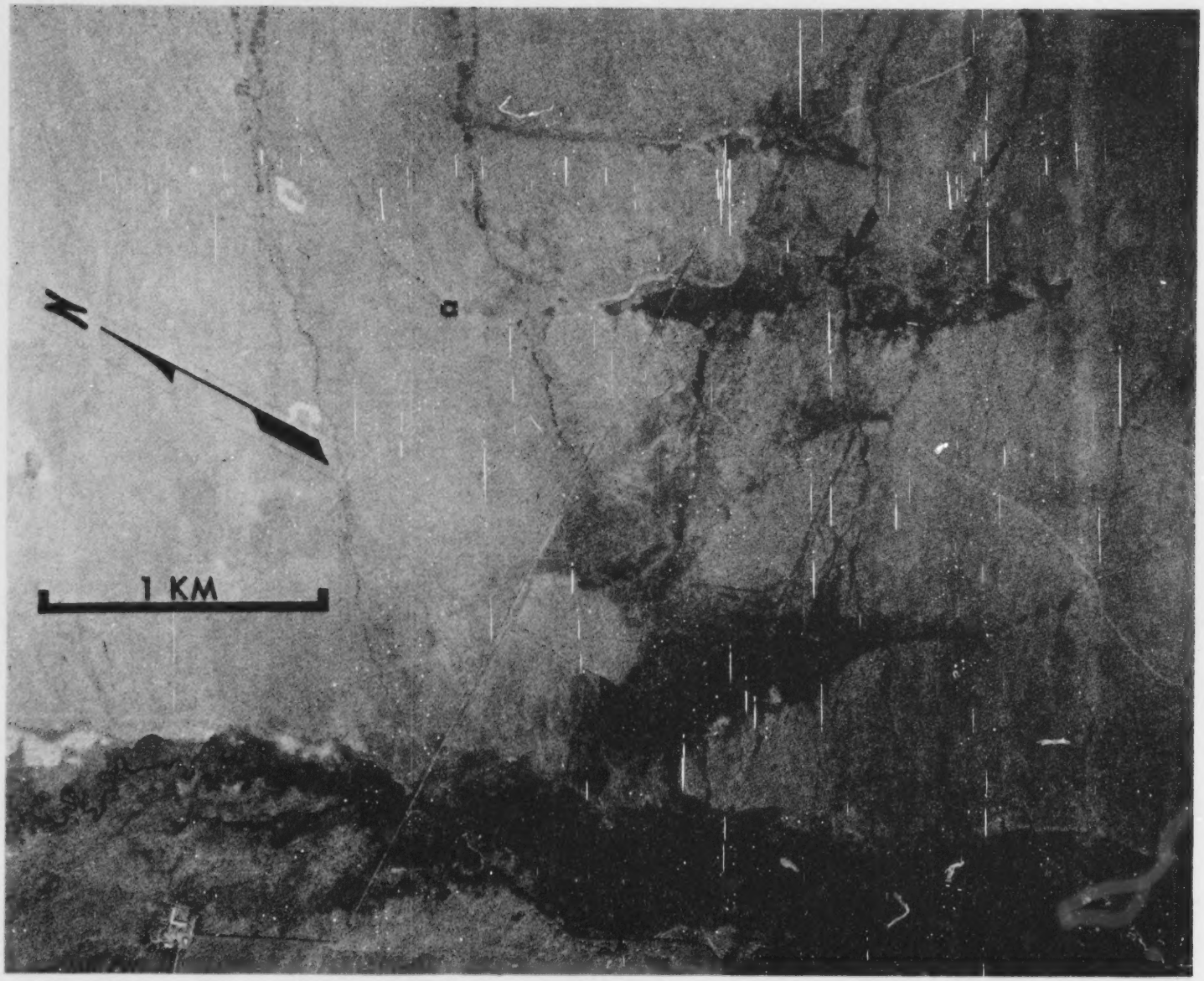


Figure 9 Low Altitude Color Aerial Photograph

Figure 10 Ground Level Photo of A Fault Scarp

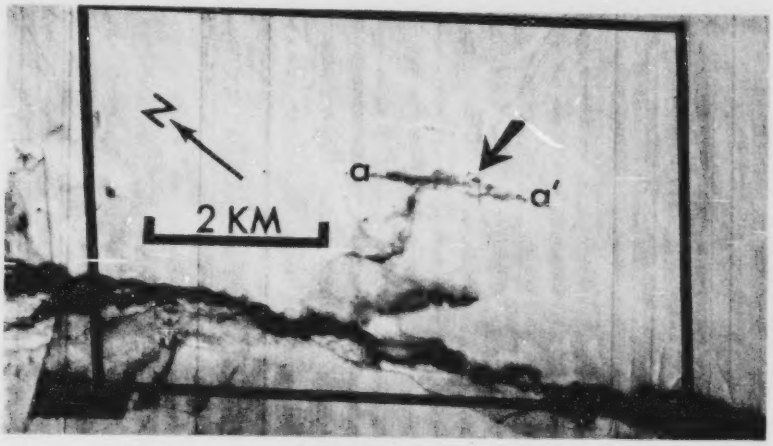


Figure 11 Thermal Infrared Scanner Imagery

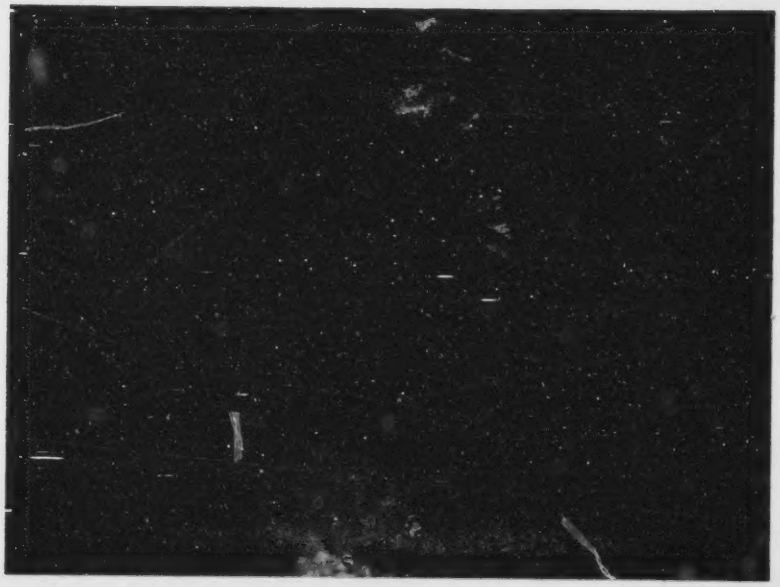


Figure 12 Low Sun-Angle Aerial Photograph

Section 2

Multispectral Photographic Facility

BACKGROUND

Multispectral photography from aircraft has become increasingly valuable in large scale observations of croplands, forests, watersheds, geological formations, and cultural features, taking advantage of the spectral characteristics or "signature" of the light reflected from individual features. Determination of types and surface moisture content of soils, of species and health of crops, of the extent of insect infestation of forests, of land use and population distribution are examples of this application. Extension of these techniques to observation from orbit has been demonstrated on earlier manned flights and shows considerable promise for: (1) wide area coverage with a uniformity of lighting conditions which is almost unachievable in aircraft survey programs, (2) for observation and analysis of large scale geological structure, and (3) for economical access to remote areas on a repetitive basis.

The Skylab Multispectral Photographic Facility consists of the following two experiments: the Multispectral Photographic Camera (Experiment S190A), and the Earth Terrain Camera (Experiment S190B).

SCIENTIFIC OBJECTIVES

Multispectral Photographic Camera (S190A)

The objective of the Multispectral Photographic Camera experiment is to obtain precision multispectral photography that will provide the basis for a wide range of user oriented studies. This photography will be an accurate record of the radiance scene. That is, the camera will provide accurate images of ground radiance variations. Specifically the objectives are:

- To acquire imaged radiance measurements of selected test sites in the photographic portion of the spectrum.
- To evaluate the usefulness of such data in generation of maps of earth features and land cover (thematic and topographic maps).
- To develop and evaluate methods of photo-optically processing such photographic radiometric imagery data.
- To evaluate 1:3,000,000 scale photography for mapping purposes.
- To measure the effects of atmospheric scattering and evaluate methods for removing these effects from the data.

It will, thereby, afford an opportunity to determine the extent to which precision and repetitive multispectral photography from space can be applied effectively to the earth resources disciplines.

Earth Terrain Camera (S190B)

The objective of the Earth Terrain Camera experiment is to obtain high-resolution photography in support of other Earth Resource Experiment Package (EREP) sensors, and user oriented studies.

Specifically, the objectives are:

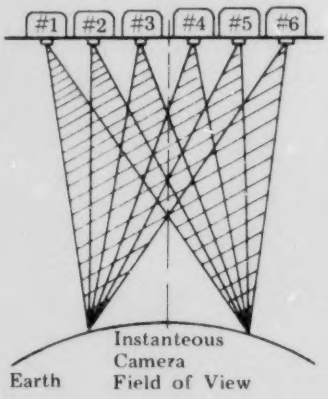
- To supply high-resolution data of small areas within the fields of view of the Earth Resources Experiment Package remote sensors to aid in interpretation of the data gathered by these instruments.
- To obtain high-resolution photography that can be used in the following areas of interest:
  - Urban and industrial planning, including the patterns and distributions of dwellings and facilities, the land use intensity, the roads, terminals, and traffic patterns.
  - The determination of pollution boundaries, lake and reservoir levels, and the effluents of rivers.
  - The boundaries of crop infestation and damage, the yield, the type and density of forested areas.
  - The determination of drainage patterns, small geologic folds, and lithographic detail.
  - The interpretation of dynamic events, such as floods, volcanos, and earthquakes.
  - Acquisition of ground truth data where ground support or aircraft are not available.
  - Investigation of mapping applications for 1:250,000 scale maps.

EQUIPMENT

Multispectral Photographic Camera (S190A)

This experiment consists of an array of six 70 millimeter cameras, precisely matched and boresighted so that photographs from all six cameras will be accurately in register. Thus, all of the features seen in one photograph can be

S190A Boresighted Camera



All camera Field of Views Identical at Time of Exposure, Thus all Features Are in Register

simultaneously aligned with the same features in the photographs from the other cameras. Six high-precision f/2.8, 21.2 degree field of view lenses with matched distortion and focal length will be used on the cameras.

The f/2.8 lenses have a focal length of 0.1524 meters (6 inches) providing an approximately 160 kilometer (88 nautical mile) square surface coverage (26,570 square kilometers) from the 436 kilometer (235 nautical mile) orbit altitude. Refer to Figure 13. Shutter assemblies provide for variable aperture settings. Aperture stops are variable from f/2.8 to f/16 in 1/2 stop increments, to an accuracy of plus or minus 1.5%.

Compensation for the spacecrafts velocity in its flight path is provided to assure high resolution photographs.

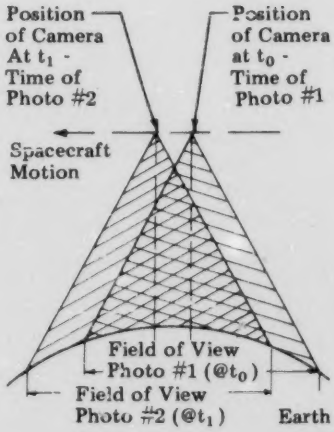
Photographs can be obtained singly, or in automatic series, at from 2 to 20 second intervals; thus allowing up to 90% overlap between frames and providing stereo photographs. Shutter speeds available are 2.5, 5, and 10 milliseconds (repeatable to 2.5%) and the six shutter mechanisms are synchronized within 0.4 milliseconds accuracy.

The resolution (smallest object detectable on the ground) will vary with the type of film used; the range of resolution extends from 23.77 meters (78 feet) with high resolution color film to 67.97 meters (223 feet) with infrared black and white film.

The cameras utilize 70 millimeter film of a 4-mil base in cassettes holding approximately 400 frames each. Photographic format size is 0.057 meters (2.25 inches) square. The cameras are designed for the following bandwidth/film combinations.

Bandwidth, Micrometers	*Film Type*
0.7 to 0.8	IR Aerographic Black and White (B&W)
0.8 to 0.9	IR Aerographic B&W
0.5 to 0.88	Aerochrome IR color
0.4 to 0.7	Aerial color (high-resolution)
0.6 to 0.7	PANATOMIC-X Aerial B&W
0.5 to 0.6	PANATOMIC-X Aerial B&W

Within these general spectral regions, various film and filter combinations will be used. The spectral regions designated above were selected to separate the visible and photographic IR spectrum into the bands that are expected to be most useful for multispectral analysis. This selection was based on the experience gained in multispectral photographic studies and experiment programs such as the NASA Earth Observations Aircraft Program, and the performance of Apollo


Position of Camera At t_1 - Time of Photo #2
Position of Camera at t_0 - Time of Photo #1
Spacecraft Motion
Field of View Photo #1 ($@t_0$)
Field of View Photo #2 ($@t_1$)
Earth

Camera Exposures Providing Scene Overlap (Up to 90%), Thus Providing Stereo Pairs For Stereo Viewing

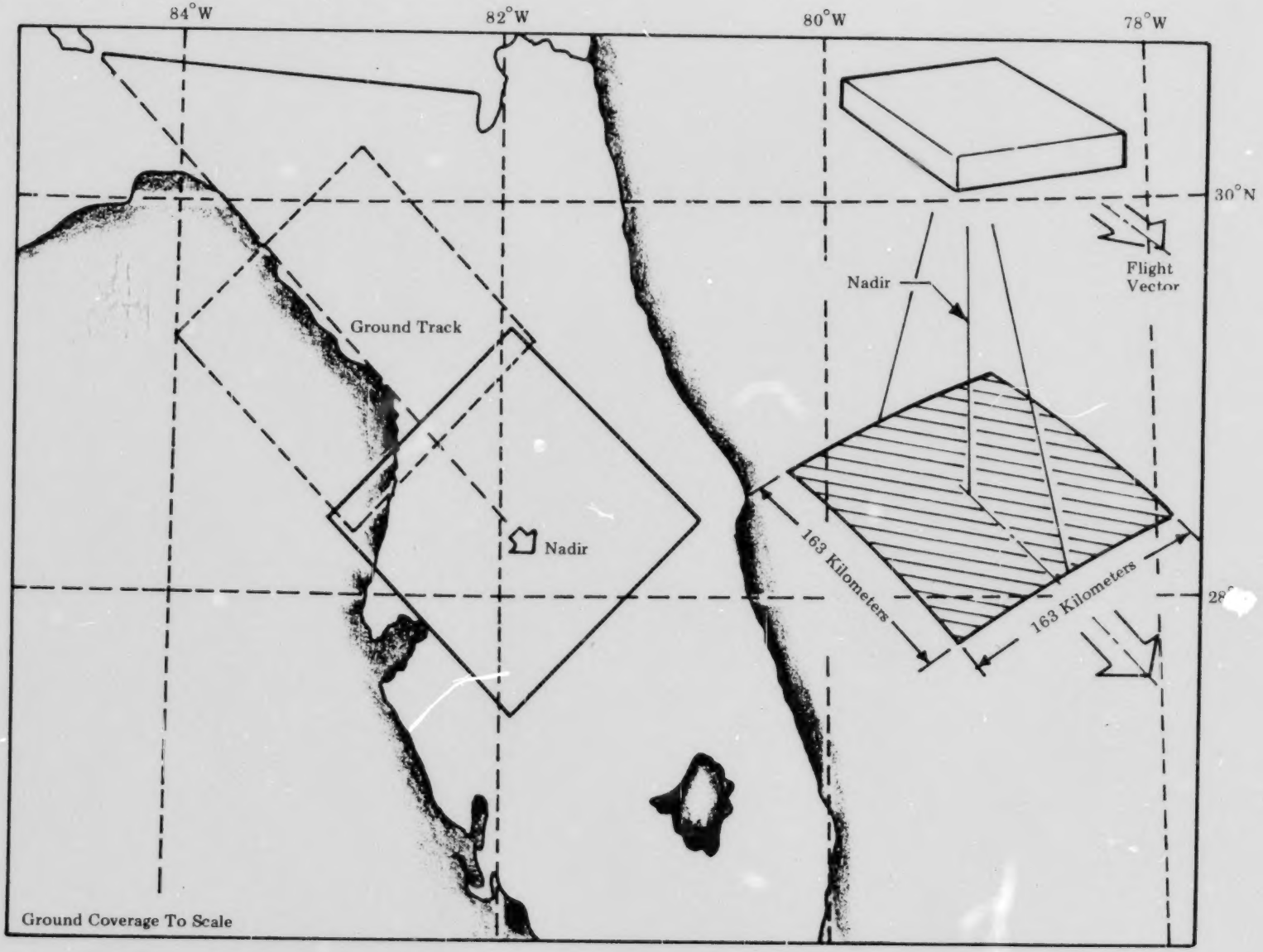


Figure 13 The S190A Multispectral Photographic Camera Photography Ground Coverage

experiment S065. The two color films will enhance the study by providing a pre-registered crosscheck of the B&W imagery in two proven color combinations. Although the cameras are designed primarily for certain film and filter combinations, the experiment system will provide the capability for evaluating various other film and filter combinations over several types of test sites (including combinations of filters on each lens).

Spectral radiometric calibration will be performed on each mission by photographing the moon within four days of full moon, during a passage of the dark side of the earth orbit.

A film vault is used for storage of the film when photographs are not being taken to protect the film from radiation damage.

Earth Terrain Camera (S190B)

The Earth Terrain Camera (ETC) will be mounted in a scientific airlock in the orbital workshop module during operation. The scientific airlock is used as a window for viewing the earth's surface. The camera is equipped with a f/4 lens with a focal length of 0.4572 meters (18 inches), providing ground coverage of approximately 109 kilometers (59 nautical miles) square surface coverage (11,881 square kilometers area) from the orbital altitude. Refer to Figure 14.

Compensation for spacecraft forward motion is provided. Sequence photography rates of 0 to 25 frames per minute are possible, thus providing up to 85% overlap between frames and providing stereo photography. Shutter speeds available are 1/100, 1/140 and 1/200 of a second.

The camera utilizes 0.127 meter (5 inch) film of 2.6 mil base supplied in cassettes of approximately 450 frames each. The picture size is 0.1143 meters (4.5 inches) square. The camera is designed to utilize the following film types and filters:

Film Type	*Wavelength, Micrometers*	*Wratten Filter No.*
Aerial color, high resolution	0.4 - 0.7	Neutral
High-definition aerial black and white	0.5 - 0.7	12
Aerochrome IR, color	0.5 - 0.88	12

The expected ground resolution for the proposed film and filter combinations will vary from 10 meters to 46 meters (37 feet to 150 feet).

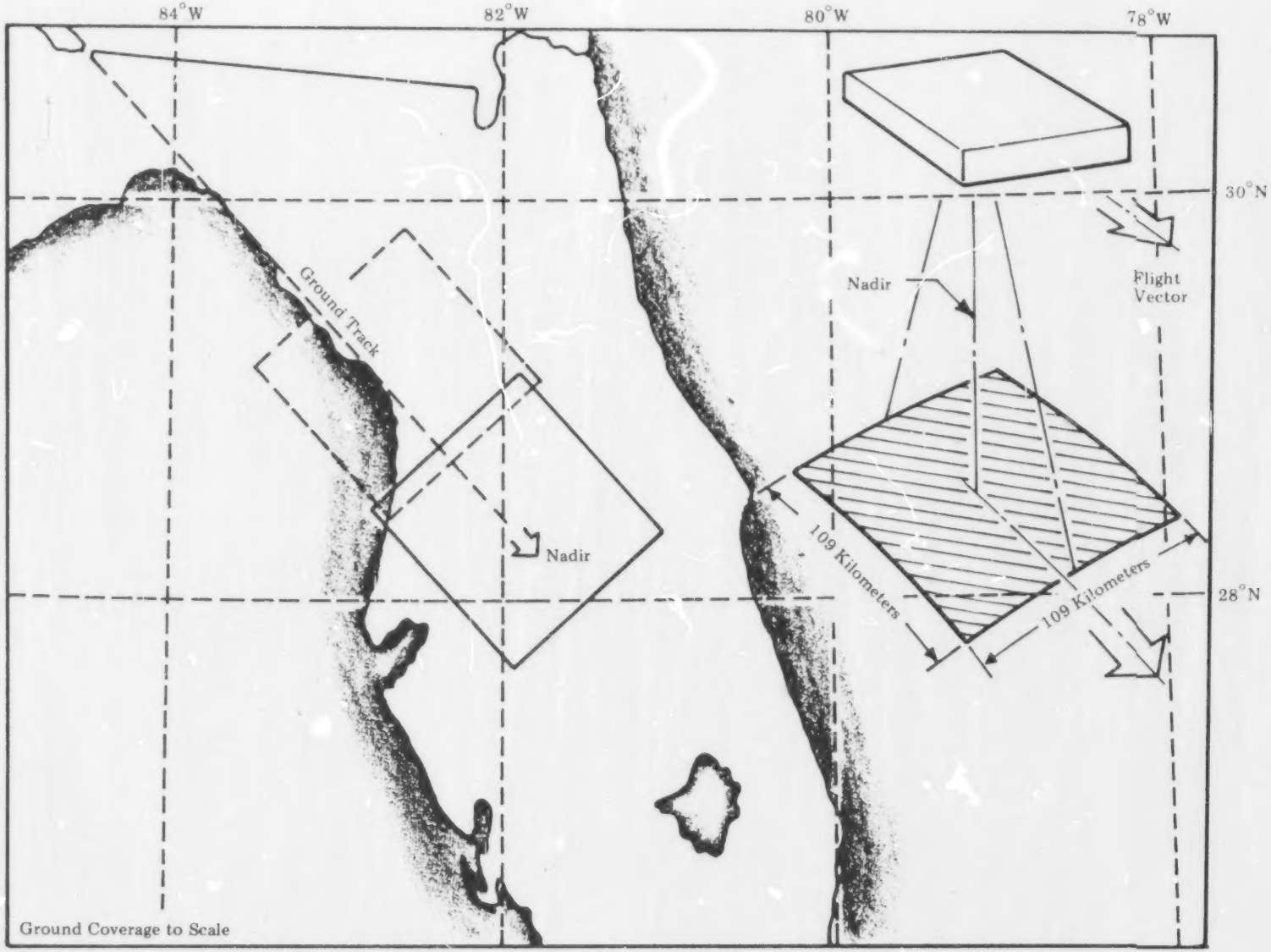


Figure 14 S190B Earth Terrain Camera Ground Coverage

As with the multispectral camera (S190A), spectral radiometric calibration will be performed on each mission by photographing the moon within four days of full moon.

PERFORMANCE

Crew Activities

The Skylab Earth Resource Experiment Package provides a manned earth observation facility with unique capabilities not presently possible with automated systems. The crewmen on board Skylab provide the ability to evaluate test site conditions, primarily weather and visibility, and revise photography activities as conditions warrant. For some phases of the operation, the astronauts will select the picture sequences based on their direct observation of the ground site using another earth resources instrument, the Viewfinder and Tracking System telescope which is a part of the infrared spectrometer experiment. Additionally, the astronauts load and unload camera film, set up the camera controls, remove the protective covers from the camera viewing port, install the S190B in the scientific airlock and make other preparations for photography operations. The S190A camera is designed for inflight maintenance of critical subsystems by the crew.

Constraints

While low sun angles may be desirable for some photography, such as emphasizing topographical feature shadows, most photography in the summer hemisphere will be obtained when the sun elevation angle is greater than 30°, and in the winter hemisphere when the sun elevation is greater than 20°. The angle at which the sun strikes the earth's surface affects not only the quantity of light reflected to the camera, but also affects the spectral quality of the light and produces shadows which may obscure some target areas.

Weather over the test site may constrain certain photographic earth observation passes, if the degree of cloud cover becomes excessive.

Certain earth observation tasks may require supporting aircraft and ground support data to be taken within a specified time relative to the orbital observations for correlation with Skylab generated data. Failure to obtain these supporting data within an acceptable time frame may further restrict performance of planned spacecraft data taking passes.

DATA OUTPUT

Following recovery of the S190A flight film from each mission, the NASA Johnson Space Center will process and

develop the film for distribution under stringent process quality controls to insure maximum data accuracy. Each frame of the original film will be identified and marked with the mission number, roll number, and frame number. The products proposed for distribution to EREP Principal Investigators and the EROS Data Center will include second generation positive transparencies (color and black and white) and second generation direct negatives (black and white). Enlarged paper prints (up to 8" x 10" maximum) and continuous process 2X enlargements paper prints (black and white) of selected frames may also be produced.

Computer processing of the flight magnetic tape data will provide computer-compatible tapes and tabulated listing defining: (1) the latitude and longitude of the principal point and projection of the four corners of each photograph, (2) calculated frame exposure times, (3) frame number, (4) filter numbers, (5) film type, and (6) aperture settings for each exposure. Plots of the field-of-view of the camera ground track will also be available. These data outputs will be used to compile a film catalog listing for each mission.

The S190B data outputs will be similar to those previously discussed for the S190A experiment.

Section 3

Infrared Spectrometer

BACKGROUND

The atmosphere of the earth is composed of a mixture of gases (nitrogen, oxygen, carbon dioxide, argon, ozone and minor constituents) in which are suspended a wide variety of particles with a great range in size and chemical composition and which contribute to absorption and scattering of radiation. Water vapor, carbon dioxide and ozone are the principal molecules which cause radiation to be absorbed, and gaseous molecules, liquid drops and solid particles suspended in the atmosphere scatter the radiation. As a result, the radiation from a source is attenuated and the contrast between the background and the source may be degraded. This can come about in four ways:

- Radiation from the source may be absorbed by gases in the path
- Radiation from the source may be deflected or scattered by particles suspended in the path so that it appears to come from the area which surrounds the source
- The gases and particles suspended in the path may themselves radiate
- There may also be scattering into the path of the radiation. Scattering agents in the path may deflect or scatter radiation in such a way that radiation which originated at some distance from the object viewed may appear to the sensor to have originated at the source. (Refer to figure 15)

The extent to which each of these effects acts upon a beam of radiation as it is transmitted through the atmosphere fluctuates with time as meteorological conditions change. (The amount of water vapor in the path varies over a wide range, as does the amount of ozone. The numbers of solid particles and liquid drops in the atmosphere also vary within wide limits.) The resulting radiation obtained at the remote sensor differs from the radiation transmitted by the object, due to atmospheric attenuation. An example of this is the red appearance of the setting sun where the blue light has been largely scattered out of the beam in the long atmospheric path. Thus, the radiation reaching the sensor (the eye) has very little of the blue component in it, although the radiation emanating from the object being viewed did have a blue component.

The infrared spectrometer experiment is designed to make a fundamental evaluation of the applicability and usefulness of sensing earth resources from orbital altitudes, in the visible through near-infrared (i.e., 0.4 to 2.4 micrometers) and in the far-infrared (i.e., 6.2 to 15.5 micrometers) spectral regions,

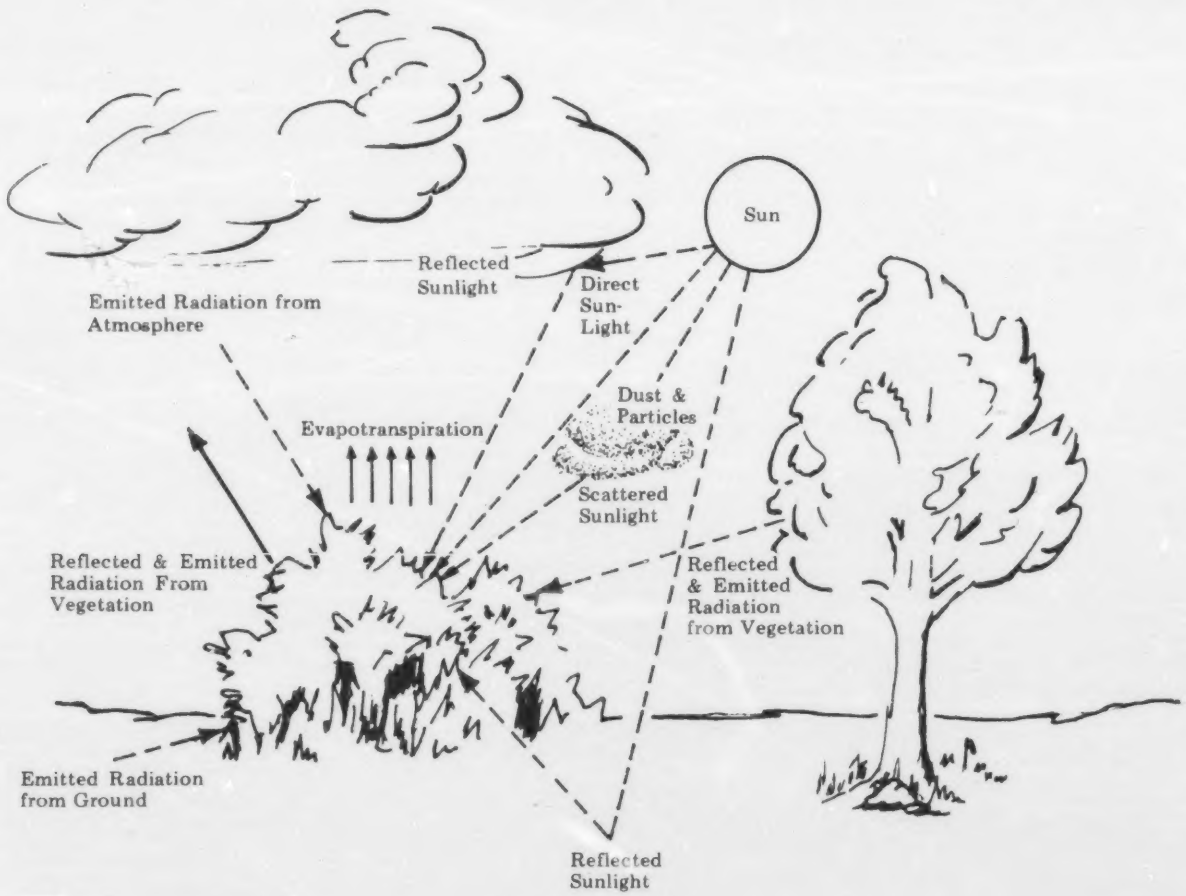


Figure 15 Reflected and Emitted Radiation Energy Exchange in a Natural Environment

and to assess the value of real-time identification of ground sites by an astronaut.

The reliability of spectral signature identification from orbital altitudes will also be determined by comparing the infrared spectrometer results with concurrent measurements from aircraft and ground test sites. This technique has the potential of providing a means of monitoring from space the extent and health of surface vegetation, without the need for spatial resolution of individual plants. Geological information and precision sea-surface temperature measurements will also be obtained.

Although a similar instrument has been used to accumulate data from aircraft flights, the resolution and the contrast in the image are significantly different for remote sensing from orbital altitudes. It follows, therefore, that development tests from spacecraft are a vital extension of similar experiments which have been conducted from aircraft. Measurements from spacecraft have many advantages of which vast areas of coverage with uniform lighting may be the most important.

SCIENTIFIC OBJECTIVES

The primary function of the infrared spectrometer is to quantitatively determine the effects of the atmospheric attenuation and radiation from surface features over a broad spectral range, and to determine the accuracy with which signals arriving at the sensor can be corrected for the atmospheric affects. These objectives will be accomplished through the collection of data concurrently in three locations for a given ground target: The solar radiation at the target will be measured on the ground; aircraft with a spectrometer similar to the one on the Skylab will obtain data from 7,620 meters (25,000 feet); and an astronaut will record spectrometer data while "tracking" the target from orbit. A comparison of these data sources, and their application into a mathematical model of the atmosphere, will be utilized to determine the atmospheric effects on the radiation from the scene. The data obtained will be calibrated in radiance and wavelength, throughout the spectral region covered by the sensor, by means of internal reference infrared sources (i.e., black bodies).

BLACK BODY— Refer to Glossary for definition.

The field of view of the Skylab Infrared Spectrometer is smaller than that of any previous satellite spectrometer, allowing the sensor to look at relatively small sites on the ground; however, this small field of view is acceptable because an astronaut will operate the sensor using a Viewfinder/Tracking System (V/TS) to identify and track ground sites, thereby keeping the spectrometer field of view fixed on the sites for several spectral scans.

By comparing the data collected from the Skylab IR spectrometer with the data taken simultaneously on the ground and from aircraft, investigators will be able to assess their requirements regarding infrared sensor capability, sensitivity, and spectral resolution, and to evaluate the utility of this application of remote sensing from space.

EQUIPMENT

The infrared spectrometer has three major elements: a Cassegrain optical system which provides an image of the scene to the other two elements; a filter wheel spectrometer which measures the intensity of the image in various spectral bands; and an optical viewfinder system which looks along the same line of sight as the spectrometer and allows the operating astronaut to view and photograph the ground site. Refer to Figure 16.

A 16 millimeter data acquisition camera will be mounted to the V/TS to allow the astronaut to photograph the site being tracked.

The spectrometer splits the incoming radiation into short wavelength (0.4 micrometers to 2.5 micrometers) and long wavelength (6.6 micrometers to 16.0 micrometers). The radiation in both channels passes through a chopping wheel that allows intermittent comparison with known calibration sources providing a baseline of radiance (refer to Figure 17). A circularly variable filter wheel transmits individual radiation bands in sequence, and then the two radiation beams pass to detectors. The detector output, the difference in radiance between the incoming radiation and the reference sources, is recorded on magnetic tape. A calibration sequence can be initiated by the astronaut which inserts calibration sources into the field of view of the spectrometer.

The V/TS consists of a telescope for astronaut viewing, a gimballed mirror for tracking and acquisition of sites, and the optics necessary to provide a focused radiation beam to the spectrometer. (The sensor field of view and astronaut tracking capabilities are illustrated in Figure 18.)

The viewfinder tracking system utilizes a telescope which picks up its image from a mirror mounted on the back of the secondary mirror in the cassegrain system. This telescope has a magnification range from 2.25 to 22.5, which allows ground coverage of 129 to 12.9 kilometers (70 to 7 nautical miles) in diameter. An internal alignment system using a collimator and alignment prism provides a precise relationship between the spectrometer and viewfinder fields of view. Refer to Figure 19.

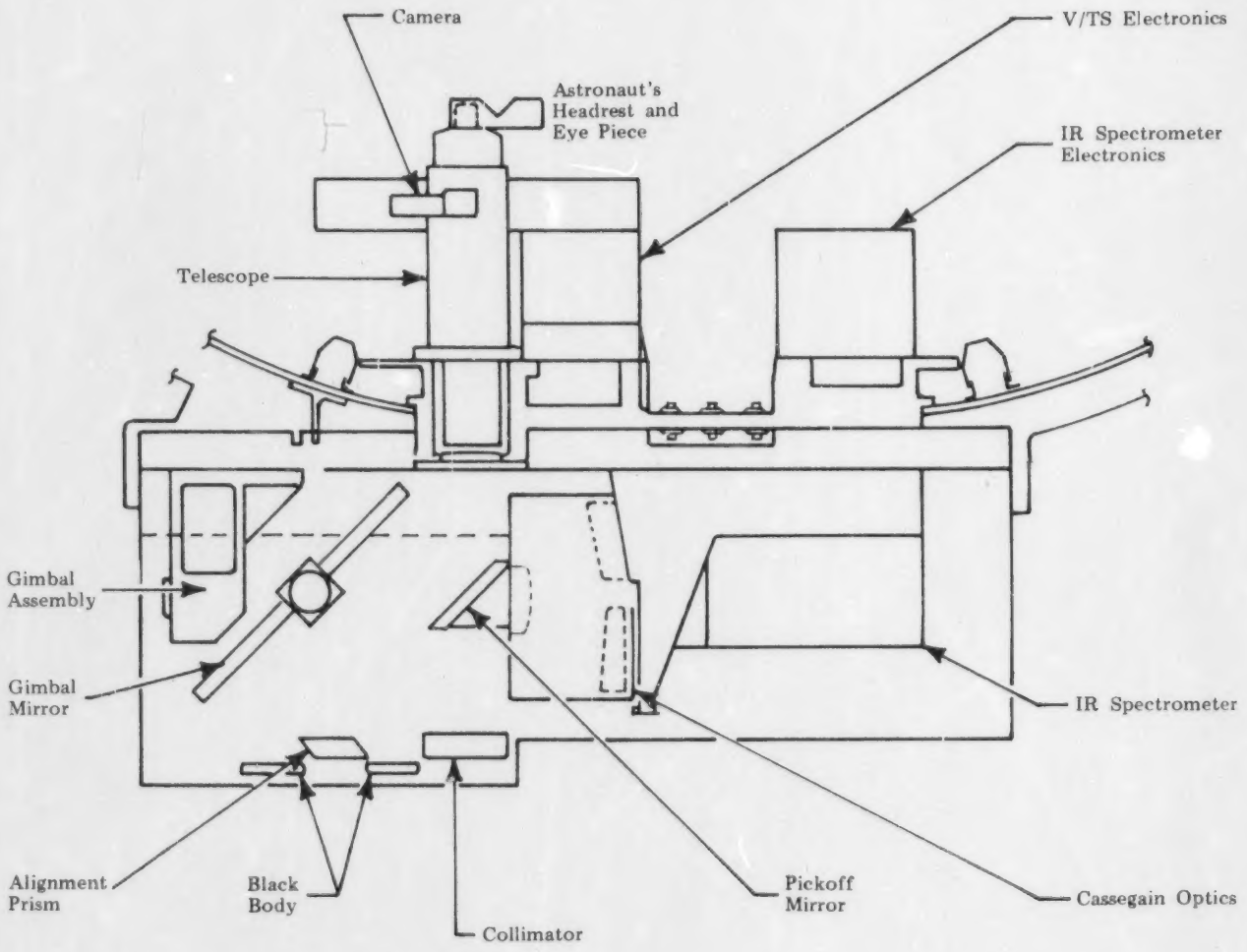


Figure 16 S191 Infrared Spectrometer

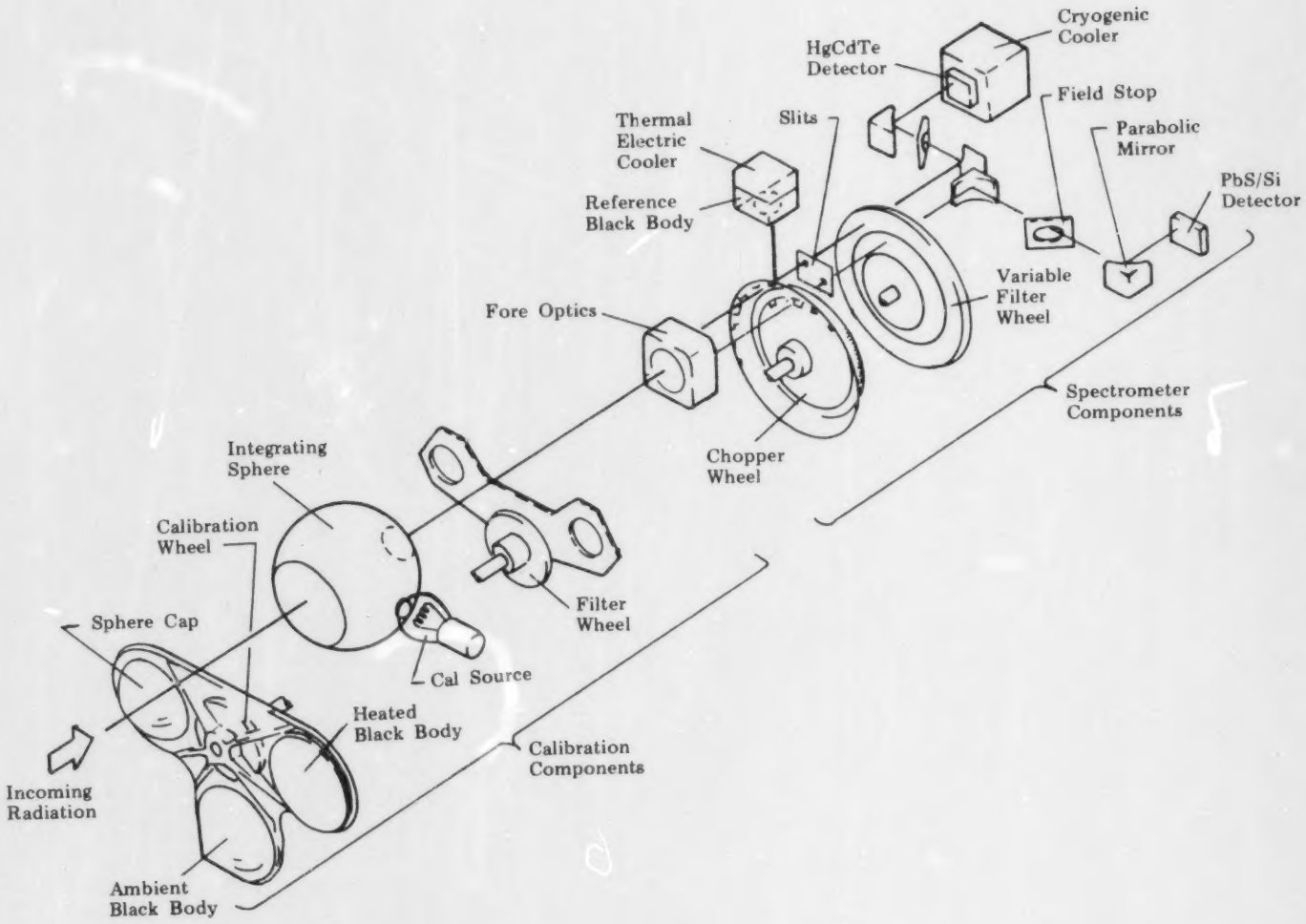


Figure 17 Spectrometer Radiation Path

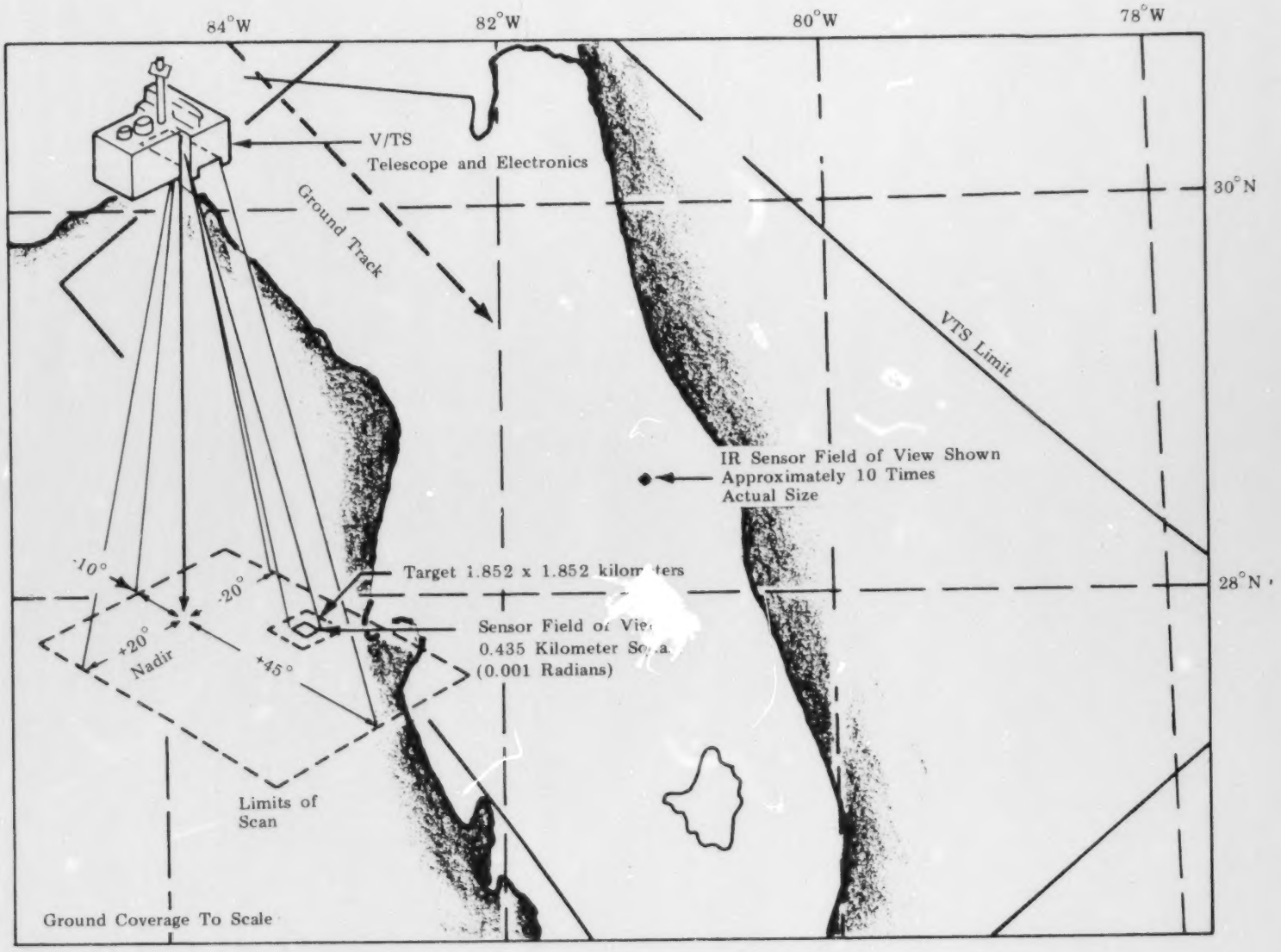


Figure 18 Ground Coverage of the S191 IR Spectrometer

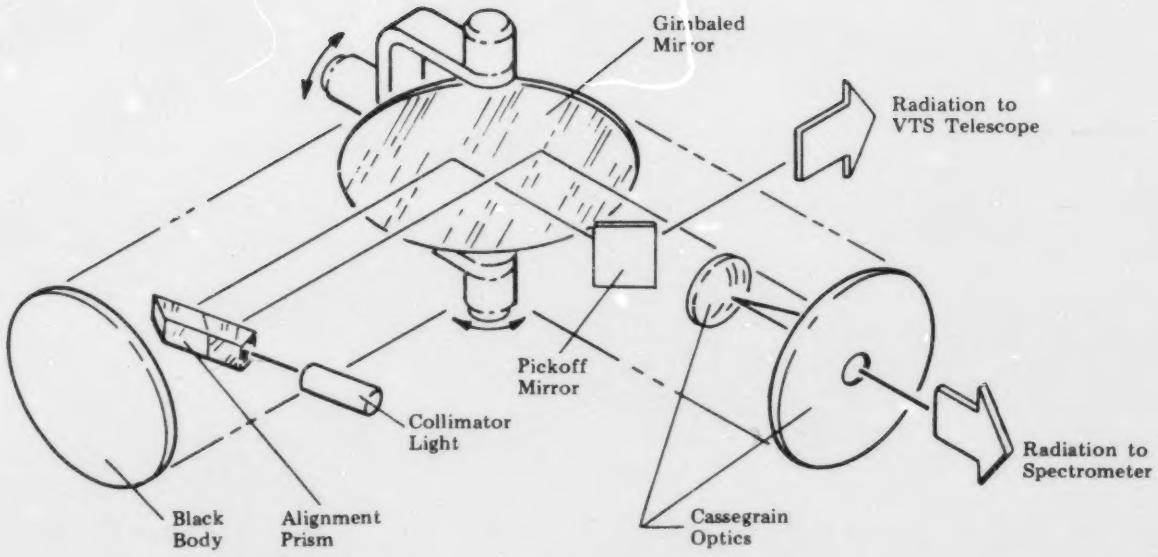


Figure 19 S191 Initial Optics and Alignment

PERFORMANCE

Crew Activities

The astronaut has less than one minute to locate the site in his field of view. In acquiring the ground sites, the astronaut must maintain a 0.435 kilometer (0.235 nautical mile) diameter resolution element within a circle of approximately 1.852 kilometer (1 nautical mile) diameter for 1 second in order to permit one complete spectral scan (refer to Figure 18).

The scene in the viewfinder will be photographed with a 16 millimeter camera attached to the viewfinder. The astronaut will assist in selecting secondary ground sites, if the primary site is obscured by cloud cover, as well as other targets of opportunity as they become available.

Constraints

Data will generally be taken when the sun-elevation angle at the ground site is greater than 20°. Because the crewmember plays a vital part in the experiment by visual recognition and tracking of the sites, it is essential that the sites have the characteristics necessary for this task, such as good lead-in points, easy recognition, and clear boundaries.

Film for the camera will be stored in a vault to protect it from the radiation levels prevailing at the Skylab altitude.

DATA OUTPUT

The S191 experiment photographic data outputs will be similar to those previously discussed in the S190 experiment section; however, the S191 film will be identified on the film leader by roll number, by agency (NASA), and by mission number. The film on each 16 millimeter roll will be edge numbered with a footage counter every fortieth frame. S191 photographic catalog tabulations will include boresight camera pulses correlated with Greenwich Mean Time (GMT), target data pulse, sun angle, spacecraft position and radiometer calibration wheel position.

The S191 sensor processed digital data outputs from NASA's Johnson Space Center will include:

Tabulations

a) Calibration wavelengths with associated responses and intermediate radiance parameters.

b) Wavelengths with calculated radiances and selected data scans.

c) Raw data from sensor data channels, with redundancy suppression optional.

Plots

a) Time history plot of sensor status data in engineering units or raw data.

b) Cross plots of aperture radiance or raw data versus wavelength.

Computer Compatible Tapes

a) Aperture radiance versus wavelength and spacecraft attitude and position. Correlated with GMT.

b) GMT correlated raw data stream.

c) GMT correlated sensor status data in engineering units or raw counts.

Section 4

Multispectral Scanner

BACKGROUND

The Multispectral Scanner (S192) experiment is designed to assess the feasibility of multispectral techniques, developed in the aircraft program, for remote sensing of earth resources from space. Specifically, attempts will be made at spectral signature identification and mapping of agriculture, forestry, geology, hydrology, and oceanography sites.

The S192 optical mechanical scanner will operate in thirteen discrete spectral bands from 0.4 to 12.5 micrometers. These bands are relatively wide and are located in spectral regions with high atmospheric transmission.

The spectral range covered by the scanner overlaps that for both the Multispectral Photographic Facility and the Infrared Spectrometer. This will permit a very useful cross check of the data resulting from these three experiments. In addition, the IR spectrometer data will hopefully provide atmospheric density profiles which would be extremely useful for correcting the primary causes of atmospheric attenuation of the multispectral scanner data.

Multispectral scanners have been flown in aircraft for several years, and promising results have been obtained for identifying and mapping vegetation and surface soils. Some progress has also been made in utilizing the remotely sensed data for assessing the health of vegetation. Achievements in this area include crop identification, crop inventory, soil and geologic mapping based on unique signatures for certain crops and soils in these bands.

SCIENTIFIC OBJECTIVES

The objectives of the multispectral scanner are as follows:

- To obtain quantitative radiance values simultaneously in several spectral bands over selected test sites in the United States and other areas.

- To evaluate the usefullness of spacecraft multispectral data in crop identification, vegetation mapping, land-use determination, studies of ocean chlorophyll content, ocean currents, water depth, identification of contaminated areas in large bodies of water, and surface-temperature mapping.

- To evaluate and determine the feasibility of using automatic data processing, spectrum matching techniques for the identification of earth resource features from space.

- To compare the results of automatic processing techniques with direct photointerpretation of scanner imagery generated from the different spectral bands.

- To compare and evaluate the imagery from the several spectral bands with the photography obtained from the Multispectral Photographic Facility experiment.

EQUIPMENT

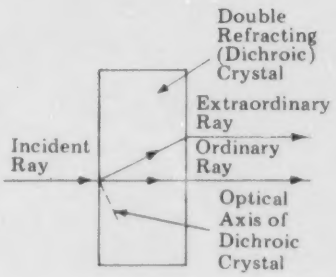
The basic instrument design is a mechanical optical scanner combined with a folded reflecting telescope used as a radiation collector.

The Multispectral Scanner will provide the capability for gathering high resolution, quantitative data on the radiation that is reflected and emitted by selected test sites in thirteen discrete spectral bands of the visible, near-IR, and thermal-IR regions of the spectrum.

The S192 instrument contains 13 detectors, each responsive to a different band, as shown below:

Band	*Wavelength Coverage, Micrometers*
1	0.41 to 0.46
2	.46 to .51
3	.52 to .56
4	.56 to .61
5	.62 to .67
6	.68 to .76
7	.78 to .88
8	.98 to 1.08
9	1.09 to 1.19
10	1.20 to 1.30
11	1.55 to 1.75
12	2.10 to 2.35
13	10.20 to 12.5

Incoming radiant energy is collected by a 0.43 meter (17 inch) spherical collecting mirror that is the major element of a folded reflecting telescope; the outer annulus of the field of view is scanned by a rotating pair of mirrors, passed through a reflective Schmidt corrector mirror and constrained to pass through a field stop which acts as the entrance slit of a prism spectrometer. A dichroic mirror is used to separate the radiation in bands 1 to 12, (short wavelength) inclusive, from the long wave length thermal band (band 13). Refer to Figure 20 for a schematic diagram of the optic system.



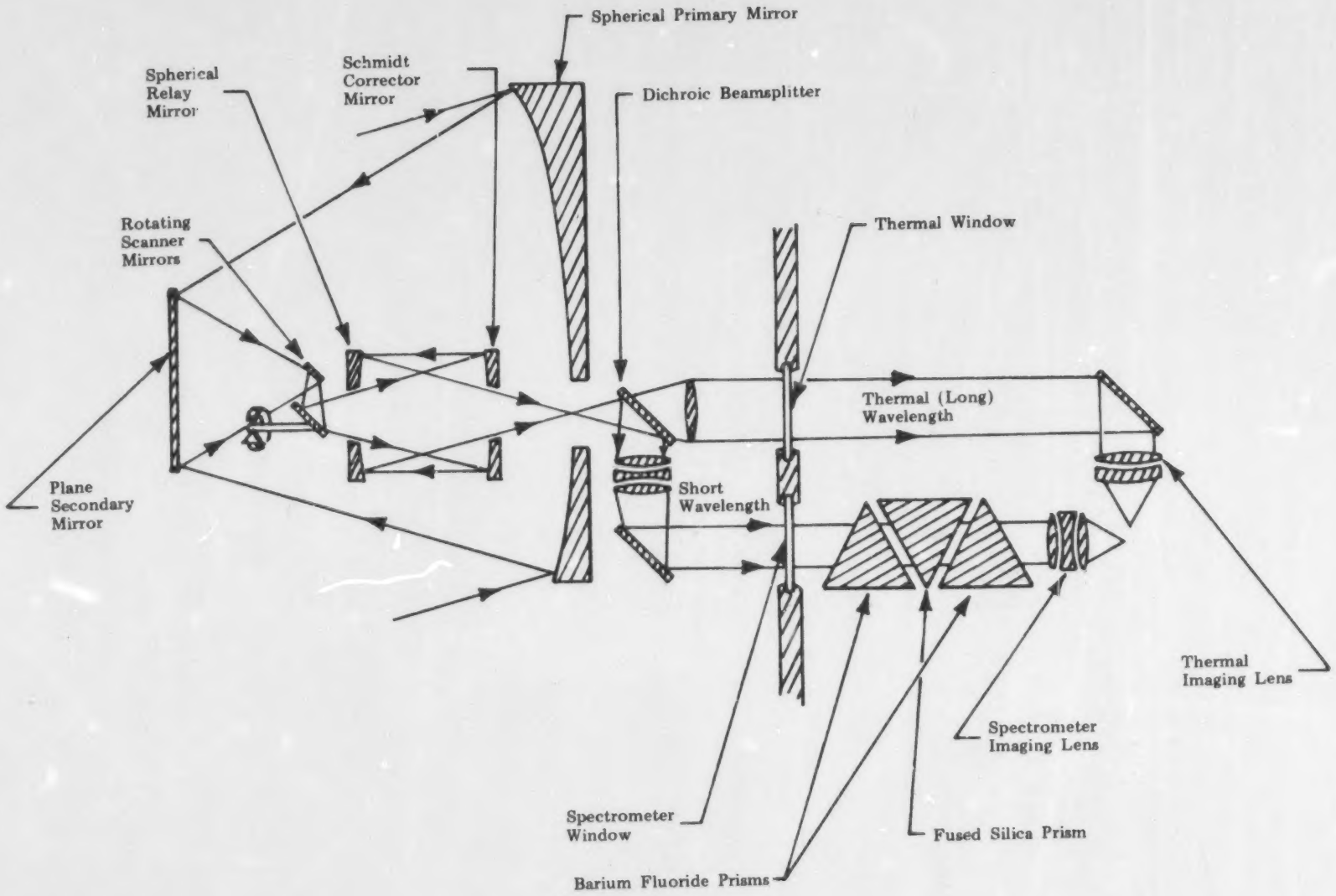


Figure 20 S192 Multispectral Scanner Optical Schematic

The short wavelength radiation (bands 1 to 12) is dispersed by a subtractive-type dispersion double prism, and the various bands are brought to focus at different positions in the focal plane of the spectrometer. The radiation from bands 1 to 12 is then detected by a mercury-cadmium-telluride (Hg:CdTe) semiconductor detector array, cooled to 92°K. The detector outputs are then amplified through the preamplifier stage before any electrical transmission takes place.

°K = degrees Kelvin thermometric scale; 0°K is absolute zero, and equals minus 273.13°C or minus 459.4°F.

Each channel is calibrated 100 times per second. The calibration reference for the visible and near-IR wavelengths is provided by a tungsten lamp. For the thermal IR wavelength, two blackbody references are provided which operate in the range of 240°K to 320°K.

The Multispectral Scanner has a conical line scan with an instantaneous square field of view of 0.182 milliradians (79.25 meter square area ground coverage). Although the scan assembly rotates a full 360 degrees, only the forward 110 degree portion of the scan is used for obtaining data. The radius of the scan circle is 41.85 kilometers (22.6 nautical miles), providing a swath width of 74.08 kilometers (40 nautical miles) for the 110 degree portion used for taking data (refer to Figure 21).

PERFORMANCE

Crew Activities

Astronauts will operate the Multispectral Scanner in accordance with flight plan timelines. However, the astronaut can vastly increase the amount of useful data recorded by only taking data under relatively clear conditions and by limiting the data taken to areas of interest, including some highly instrumented test sites and also targets of opportunity. This can be done by utilizing the infrared spectrometer viewfinder telescope to evaluate test site conditions in real time during an earth observation pass.

Constraints

The operating constraints for this experiment consist primarily of obtaining data over the specific test site with an acceptable degree of cloud cover, and generally with a sun elevation at the test site equal to or greater than 30°.

DATA OUTPUT

The sensor data requires extensive computer processing of the digital data upon recovery of the flight data tapes. Some representative types of data outputs that will be available

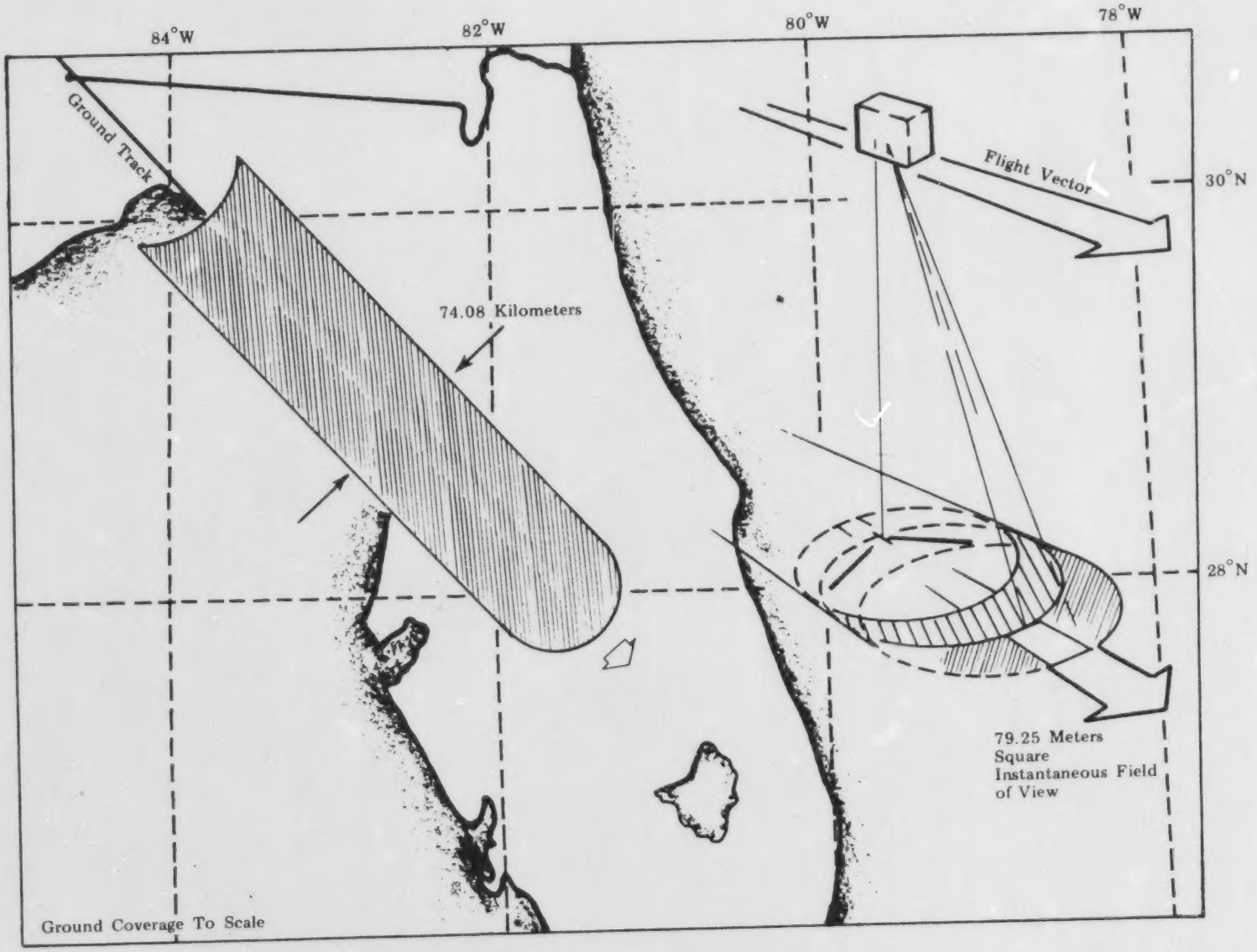


Figure 21 Ground Coverage of the S192 Multispectral Scanner

from the NASA Johnson Space Center processing facility include:

Computer Compatible Tapes

a) Edited raw data stream correlated with GMT.

b) Calculated aperture radiance (either high or low sample rate), spacecraft attitude and position, and location of sensor field-of-view. All correlated with GMT.

Tabulations

a) Time history of sensor status data, and scientific calibration data in engineering units.

b) Location of sensor field-of-view and time.

c) Location of sensor field-of-view for every 1000th scan line (corresponding to screening film) and time.

Plots

a) Thermal contour plots.

b) Centerline and both side lines of the sensor field-of-view for a specified time on a latitude-longitude grid with time annotation.

Films

a) Film images from radiometrically corrected data. Earth rotation and scan line delay correction will be performed.

b) Black and white screening film.

c) Color composites of up to three data channels.

d) False color film based on amplitute ranges from a single channel.

Section 5

Microwave Radiometer/ Scatterometer and Altimeter

BACKGROUND

Radar, which had its beginning in the nineteenth century with the early experiments of H. Hertz, reached its height as a full fledged technology in World War II. Radar is utilized as a remote sensor since it is not affected by darkness and is generally impervious to conditions such as haze, fog, rain and snow. It, therefore, has the capability to "see" (penetrate) through conditions which visual and infrared radiation can not. Radar frequencies range on the low end from VHF of approximately 25 megahertz (MHz) through UHF, L, S, C, X, Ku, K, Ka and Millimeter bands of around 300 gigahertz (GHz) at the high end. Microwave radiation frequencies range from 300 MHz to 300 GHz, with the Ku band ranging from 12.5 GHz to 18 GHz. The selection of a particular frequency in the design of a spaceborne microwave experiment is based on the resolution required, a practical size of the antenna, and upon minimized atmospheric attenuation by atmospheric gases and water vapor. As the microwave frequency is increased, resolution improves, the size of the antenna decreases for a fixed resolution and there is an increase in attenuation caused by the atmospheric gases and water vapor. Microwave devices may be either active or passive in nature and experiment S193 combines both active and passive elements all operating in the Ku band at 13.9 GHz and is essentially three experiments in one (i.e., a radar scatterometer, a radiometer and a radar altimeter).

The scatterometer transmits a radar signal and its "echo" or return signal is sensed and is a function of surface roughness, and dielectric properties. In the case of ocean overflights, where the dielectric properties are constant, the return is a function of sea surface roughness caused by winds.

The radiometer senses the surface emitted microwave brightness temperature, or radiation intensity which will be a function of material emissivity, dielectric properties and roughness. The sensed radiation will be affected by atmospheric attenuation.

BRIGHTNESS TEMPERATURE — Refer to Glossary for definition.

The experiment operation is based on near simultaneous measurements of the effect of scattering on radar echoes of signals transmitted from Skylab, and measurements of radiation emission of the land and oceans in the microwave band on a global scale. The scattered radar echo (back scattering) provides a measurement of the combined effect of the dielectric properties and roughness of the terrestrial surface. The passive microwave emission produces a measurement of the combined effect of the dielectric properties, roughness and brightness temperature of the terrestrial surface. The emissivity (i.e., a measure of the amount of energy of a certain frequency emitted in a particular direction from an object with known dielectric properties

and at a particular temperature) is a function of the surface roughness of the body. Thus, the microwave radiometer/scatterometer experiment can extract information about the roughness and apparent temperature of the terrestrial surface, when the dielectric properties are known. The surface dielectric properties of the land vary a great deal according to material composition, moisture content and the characteristics of vegetation. Therefore, to obtain the desired information over land coverage, the dielectric properties of ground sites must be supplied concurrent with the observations made from Skylab by other experimental means.

Since the dielectric properties of oceans are essentially the same everywhere, the microwave radiometer/scatterometer experiment is suitable for establishing global patterns of ocean surface roughness and brightness temperatures. In turn, the ocean surface roughness patterns can be related to ocean surface wind patterns which can be used to aid ship navigation and numerical weather prediction in oceanography and meteorology.

Radar ocean backscattering and radiometric measurements have been carried out extensively by aircraft which usually have high spatial resolution, but limited coverage. Spaceborne microwave radiometer/scatterometer measurement offer extensive coverage with useful resolution. The measurements made by NASA Earth Resources Aircraft scatterometer studies have led to the following conclusions:

- Increasing wind speed and the related ocean surface wavelets result in increasing values of returned energy for all angles of incidence between 15 and 45 degrees.
- As wind velocity increases, the increases of returned energy are substantial.
- The radar return is higher for upwind-downwind conditions than for crosswind conditions.

The spaceborne microwave radiometer/scatterometer measurement results will be used to verify these aircraft findings at near the same radar operating frequency (13.9 GHz), and to establish the feasibility of determining patterns of ocean surface roughness and wind fields on a global scale.

An altimeter experiment that shares the antenna assembly of the microwave radiometer/scatterometer experiment is also included in this experiment. The main purpose of the altimeter experiment is to obtain information about ocean sea state effects on transient radar pulse characteristics. Data will be used for future altimeter design for earth physics and geodetic applications.

SCIENTIFIC OBJECTIVES

The purpose of this experiment is to study the application of active and passive microwave sensors to earth resources investigations from orbital altitudes. The microwave radiometer/scatterometer objectives in ocean, land and instrument studies are:

- Measure, near simultaneously, the radar backscattering characteristics and microwave emission from varying ocean surfaces and their inter-relationships.
- Establish global patterns of ocean surface roughness, of wave conditions and of surface wind fields.
- Identify areas of clouds and rain over the ocean and obtain atmospheric attenuation data to aid in weather prediction.
- Map snow and ice cover and seasonal advances and retreats, gross vegetation regions and their seasonal changes, extent of recent rainfall and flooding in remote regions.
- Determine whether gross differences between major world biomes may be detected with sufficient precision to be valuable.
- Determine the feasibility of measuring differences in soil types and texture to the precision needed for water runoff studies, of measuring soil moisture averages over large regions and of measuring microwave radiant energy output of metropolitan areas.
- Investigate the feasibility of removing the effects of atmospheric attenuation on the scatterometer by measuring the microwave brightness temperature with both S193 and S194 radiometers.

BIOME— A complex biotic community covering a large geographic area (such as tundra, desert, coral reef, woodland, etc.) and characterized by the distinctive life forms of important climax species of plants and animals.

The purpose of the altimeter is to obtain precise altitude measurements of the variation of the height of the ocean surface and land features, and correlate return waveform shapes with sea states. The altimeter has several operational modes which vary transmitted pulse width, pulse spacing and receiver bandwidths in order to provide data for design of future systems.

EQUIPMENT

The experiment consists of an antenna and a receiver for the radiometer, scatterometer and the altimeter. The radiometer and scatterometer may be operated together or independently, and the altimeter operates independently upon

astronaut command. The frequency reference is a crystal oscillator whose frequency is multiplied and mixed such that the transmitters of both the altimeter and scatterometer generate signals centered at 13.9 GHz. The receivers for each instrument also operate at 13.9 GHz. The scatterometer and altimeter have their own transmitters and generate 8 watts and 2 kilowatts respectively.

Since the antenna is capable of scanning the received signals for doppler shifting by the incorporation of filters with different center frequencies for each of five scan angles, the scatterometer design has sufficient dynamic range for determining various wind, sea state, polarization, surface roughness and surface dielectric properties, as well as storm conditions.

The radiometer senses the brightness temperature, which is based upon the thermal emittance, surface roughness, dielectric properties and atmospheric absorption, and produces radiation measurements from which brightness temperature can be derived with a resolution of approximately $\pm 1^{\circ}$K.

The altimeter will be capable of maintaining a precision of approximately 0.9144 meters (1 yard), i.e., it will be able to distinguish sea states with a resolution of one yard in average wave height. As a 11.1 kilometer (6 nautical mile) area is being studied, this must be a statistical value. The altimeter return pulse shape reproduction, as well as precision, will be used for the design of future radar altimeters. The antenna dish is 1.125 meters (44.5 inches) in diameter and the beam width is 1.5°.

The instantaneous ground coverage of the instrument is a 11.1 kilometer (6 nautical mile) circle from spacecraft altitudes. Figures 22 through 26 illustrate some of the equipment operational scanning modes.

DATA OUTPUT

S193 data outputs available from NASA Johnson Space Center computer processing of the radiometer and scatterometer digital data will include:

Computer Compatible Tapes

a) GMT correlated radiometer aperture radiance, scatterometer backscattering coefficients; spacecraft attitude, altitude, position; and velocity. Center of the sensor field-of-view, and sensor status data in engineering units.

b) GMT correlated raw data stream.

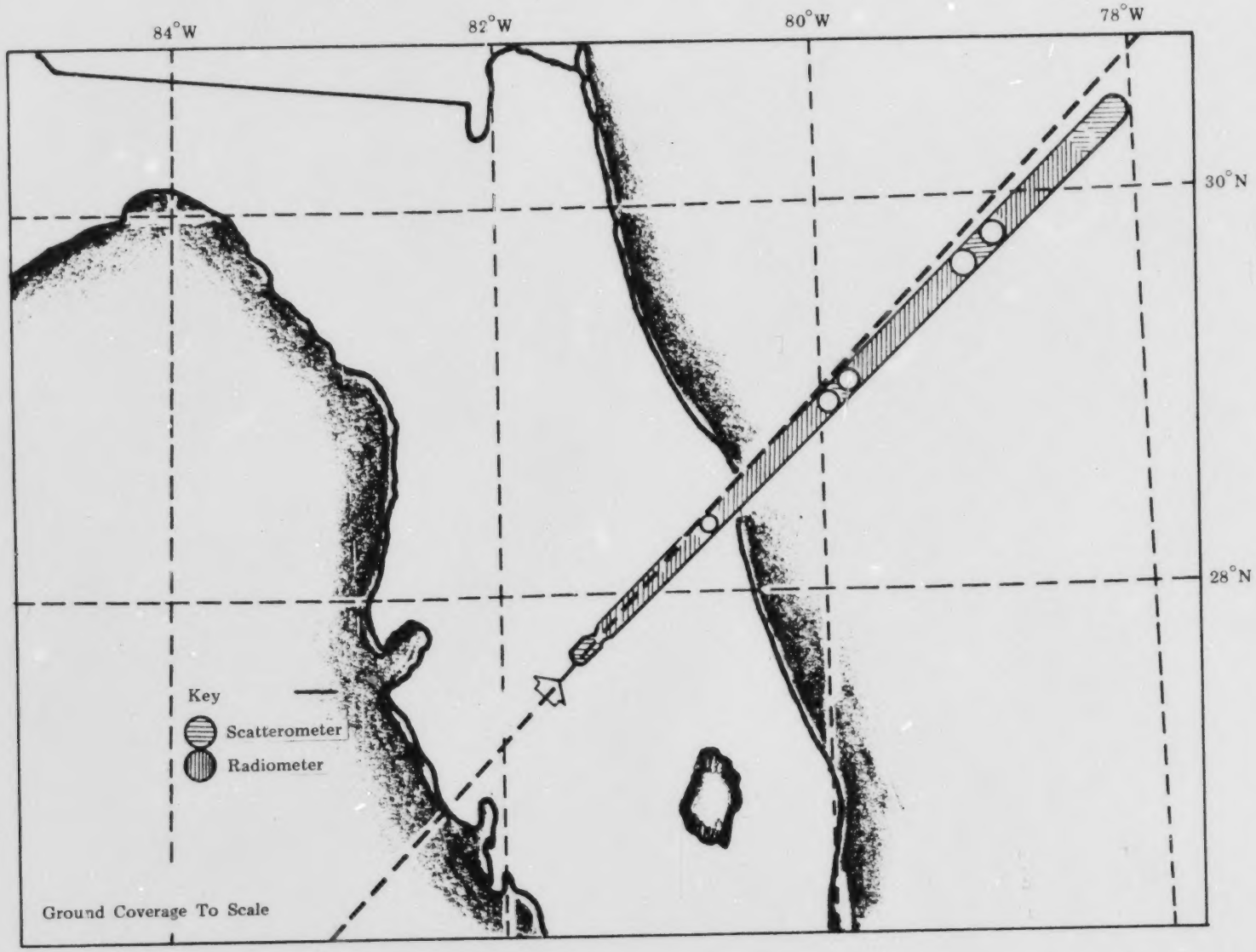


Figure 22 In-track Contiguous Scanning Mode of the S193 Microwave Radiometer/Scatterometer

Figure 23 In-track Noncontiguous Scanning Mode of the S193 Microwave Radiometer/Scatterometer

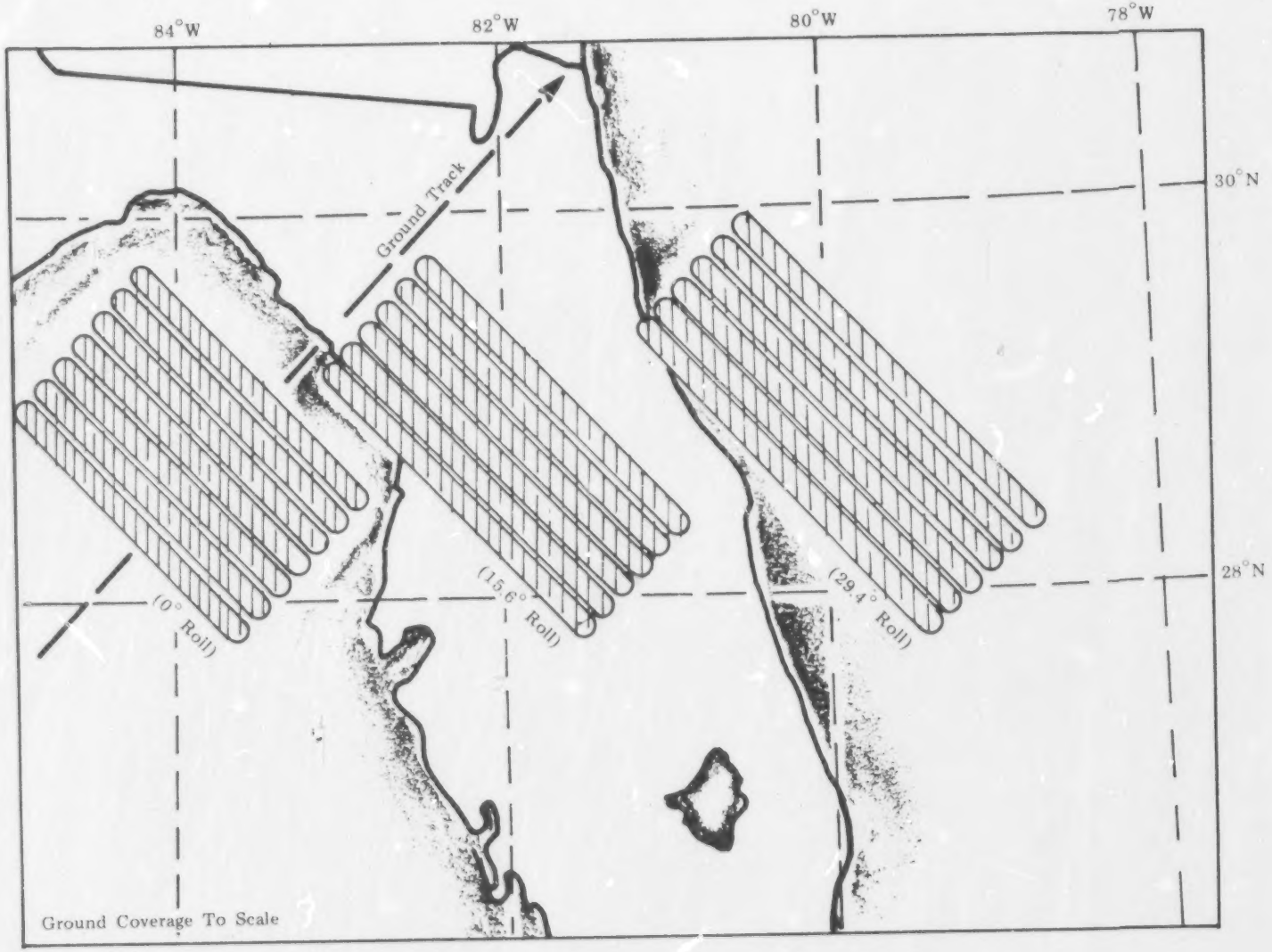


Figure 24 Cross-track Contiguous Scanning Mode of the S193 Microwave Radiometer/Scatterometer (0° Elevation Angle and at Different Roll Angles)

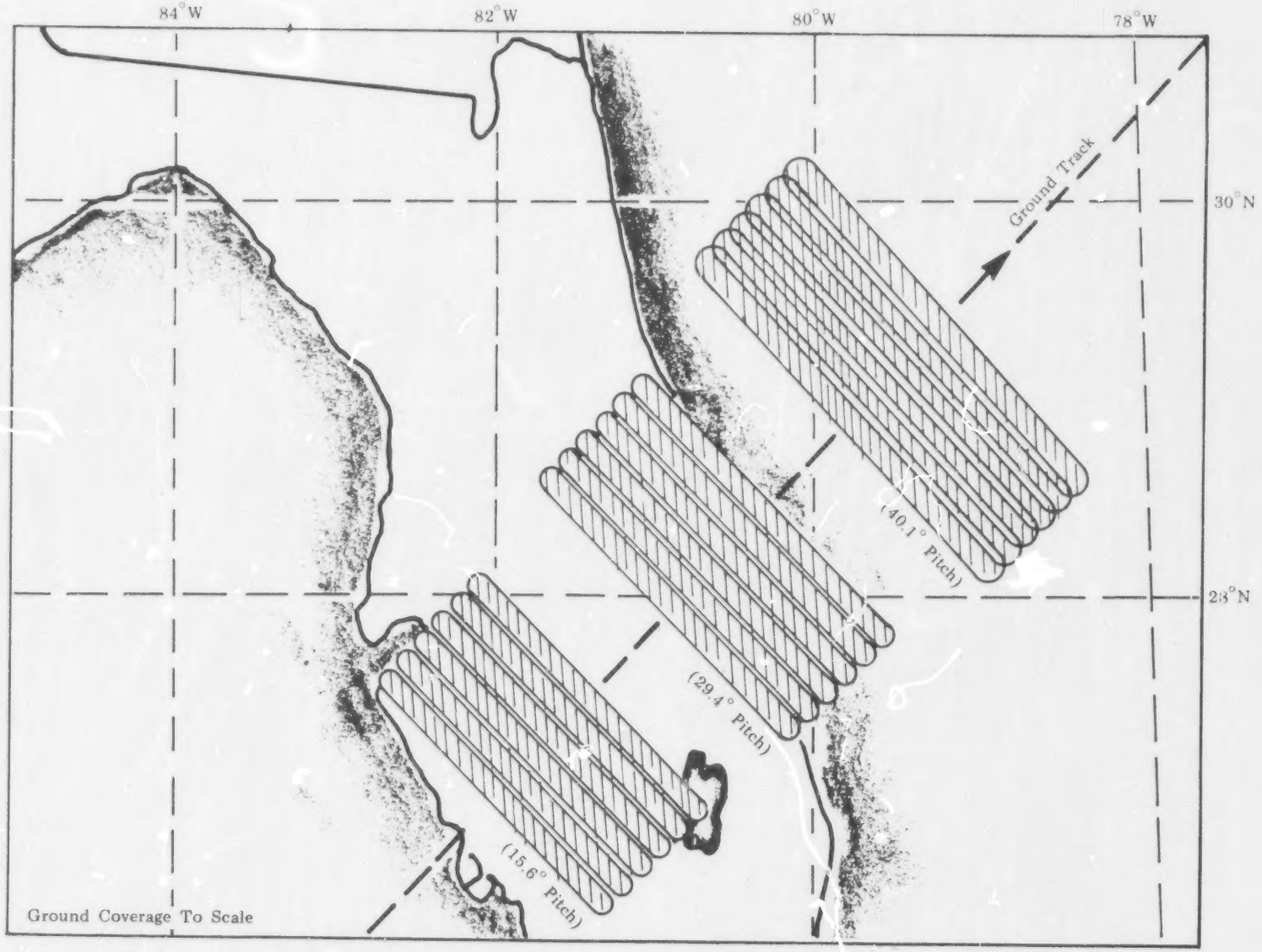


Figure 25 Cross-track Contiguous Scanning Mode of the S193 Microwave Radiometer/Scatterometer (Various Nonzero Pitch Angles)

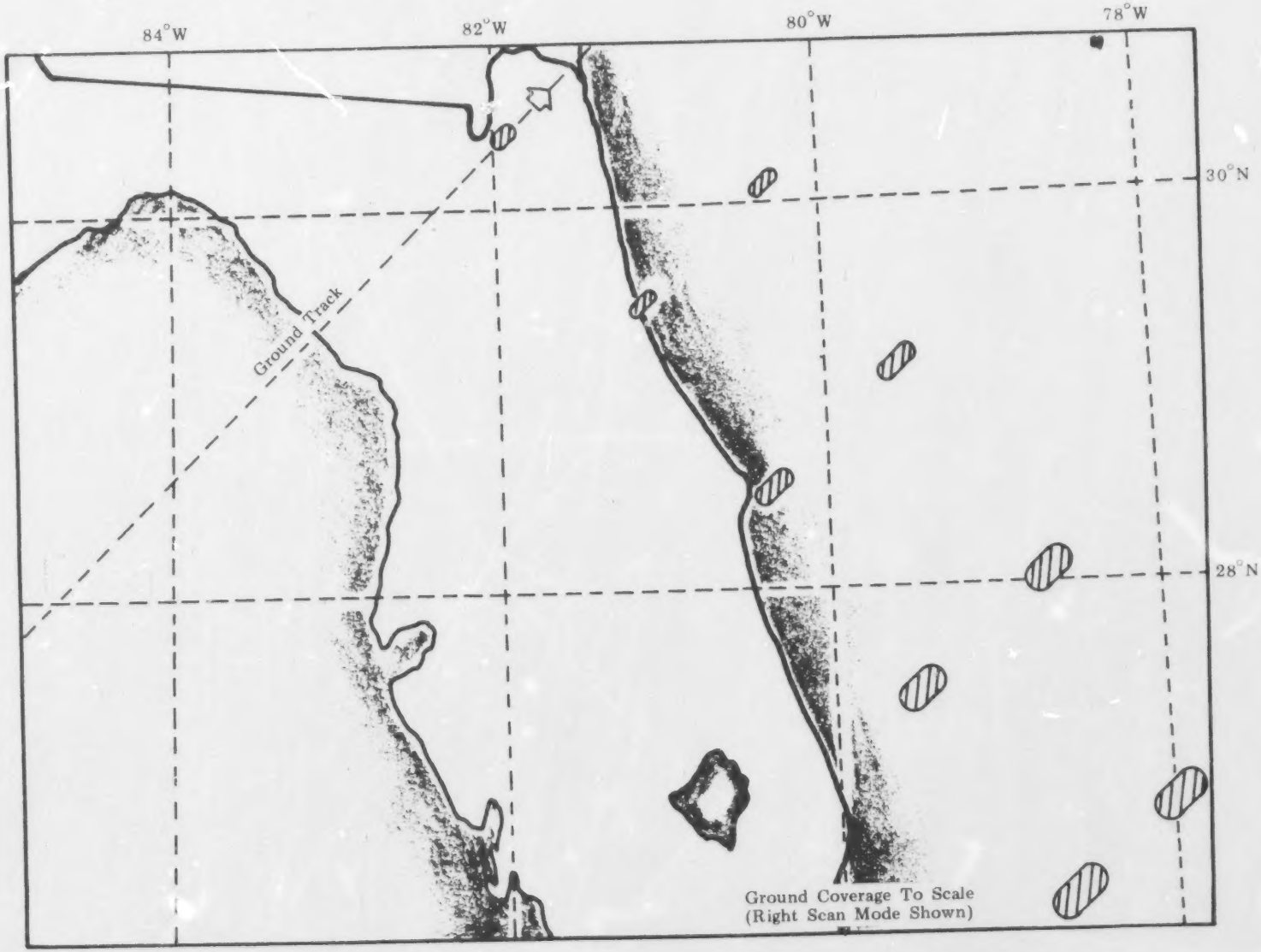


Figure 26 Cross-track Noncontiguous Scanning Mode of the S193 Microwave Radiometer/Scatterometer

Tabulations

a) Time history tabulation and plot of selected segments of raw radiometric temperature and raw backscattering data.

b) Tabulation of geodetic latitude and longitude of center of sensor field-of-view as a function of time.

c) Tabulation of averaged scatterometer backscatter in a given time interval.

d) Tabulation of averaged radiometer antenna temperature in a given time interval.

Plots

a) Plots of the sensor field-of-view on a latitude-longitude grid with time annotations. The sensor dwell position will be indicated with a point representing the sensor beam center.

b) Scatterometer backscattering as a function of angle of incidence.

c) Radiometer antenna temperature as a function of angle of incidence.

d) Scatterometer backscattering for each pitch offset angle as a function of roll angle for each polarization combination.

e) Radiometer antenna temperature for each pitch offset angle as a function of roll angle for each polarization combination.

S193 data outputs available from computer processing of the altimeter data will include:

Computer Compatible Tapes

a) Raw data stream and sensor status data correlated with GMT.

b) GMT correlated uncorrected backscatter, time history of automatic gain control voltage, spacecraft attitude and altitude, location of center of sensor field-of-view, the angular difference between the center of the sensor field-of-view and the spacecraft nadir point, and sensor status data. All data in engineering units.

Tabulations

a) Time history tabulation of altimeter range.

b) Time history tabulation of altimeter data in engineering units, with angular difference between center of sensor field-of-view and spacecraft nadir point.

c) Mean and standard deviation of altimeter range data relative to spacecraft tracking altitude data.

Plots

a) Average pulse shape for designated time intervals.

b) Plots of selected sample/hold gate pulses as a function of time.

c) Plot of position (with respect to local vertical) of the antenna as a function of time for the nadir seeker mode.

d) Plots of the sensor field-of-view at each dwell position on a latitude-longitude grid with time annotation.

Section 6

L-Band Microwave Radiometer

BACKGROUND

The L-Band Radiometer (S194) experiment is designed to supplement the Microwave Radiometer/Scatterometer and Altimeter (S193) experiment in measuring the brightness temperature of the earth's surface along the spacecraft ground track. The S194 experiment is basically the same in operating principle as the radiometer portion of the S193 experiment, except the operating frequency is changed from 13.9 GHz to 1.42 GHz. The primary function of the experiment is to complement the measurement results of experiment S193 by taking into consideration the effect of water vapor on radiometric measurements. By using two frequencies simultaneously in measurements, corrections can be made on radiometric data to remove the water vapor effects.

The instruments to be used in this experiment are patterned after those which have been used in the NASA Earth Resources Aircraft Program.

SCIENTIFIC OBJECTIVES

The objective of the L-Band Radiometer experiment is to evaluate the applicability of a passive microwave radiometer to the study of the earth from orbital altitude. The radiometer will measure the brightness temperature of the terrestrial surface along the spacecraft ground track to a high degree of accuracy. The resulting temperature will be used to compile a surface brightness temperature map.

EQUIPMENT

The S194 antenna receives signals from the radiation emission of a point on the earth surface, through any intervening clouds (i.e. water vapor). The mean value of the signal can be accurately determined if it is observed long enough to gain a measurable signal. The signal is compared with the measured mean value of another signal from a calibrated source with known temperature (blackbody). The comparison constitutes the radiometric measurement and can be correlated to give a measure of the brightness temperature of the surface, if the dielectric properties and surface roughness parameters are known.

The experiment utilizes a fixed antenna that consists of an eight element by eight element planar array of dipole radiators spaced one-half wavelength apart. (One wavelength is approximately 21 centimeters.)

The antenna has a 15° half-power beam width which implies that 50 percent of the energy received by the antenna will be received in the 15° solid pyramid centered about the vertical axis.

In addition, the antenna will receive over 90 percent of the energy available in the field of view in a 36° solid pyramid. These angles are contained in the primary lobe of the antenna. The 36° angle will encompass a swath width of approximately 267 kilometers (144 nautical miles) at the 436 kilometer orbital altitude, and the signature will be influenced by the entire view area. However, the signature recorded by the instrument will be influenced to a much larger degree by the brightness of the material contained within the 15° beam width; i.e. a 110 kilometer (60 nautical mile) swath centered about the nadir point (refer to Figure 27).

Absolute sensor radiometric calibration will be acquired by viewing cold sky conditions.

PERFORMANCE

Crew Activities

The astronauts will perform instrument calibrations, operate and monitor the equipment during Skylab earth observation passes.

Constraints

The experiment will be operated over test sites where ground truth supporting data is available, and usually in conjunction with the Microwave Radiometer/Scatterometer and Altimeter (S193).

DATA OUTPUT

The S194 sensor digital data will be computer processed by the NASA Johnson Space Center upon recovery of each flight magnetic tape. Some typical data outputs for the S194 data include:

Computer Compatible Tapes

a) GMT correlated raw data stream.

b) GMT correlated antenna temperature, spacecraft attitude and position, location of sensor field-of-view, and sensor status data. All data in engineering units.

Plots

a) Time history plots of radiometric antenna temperature.

b) Time history plot of the raw data stream.

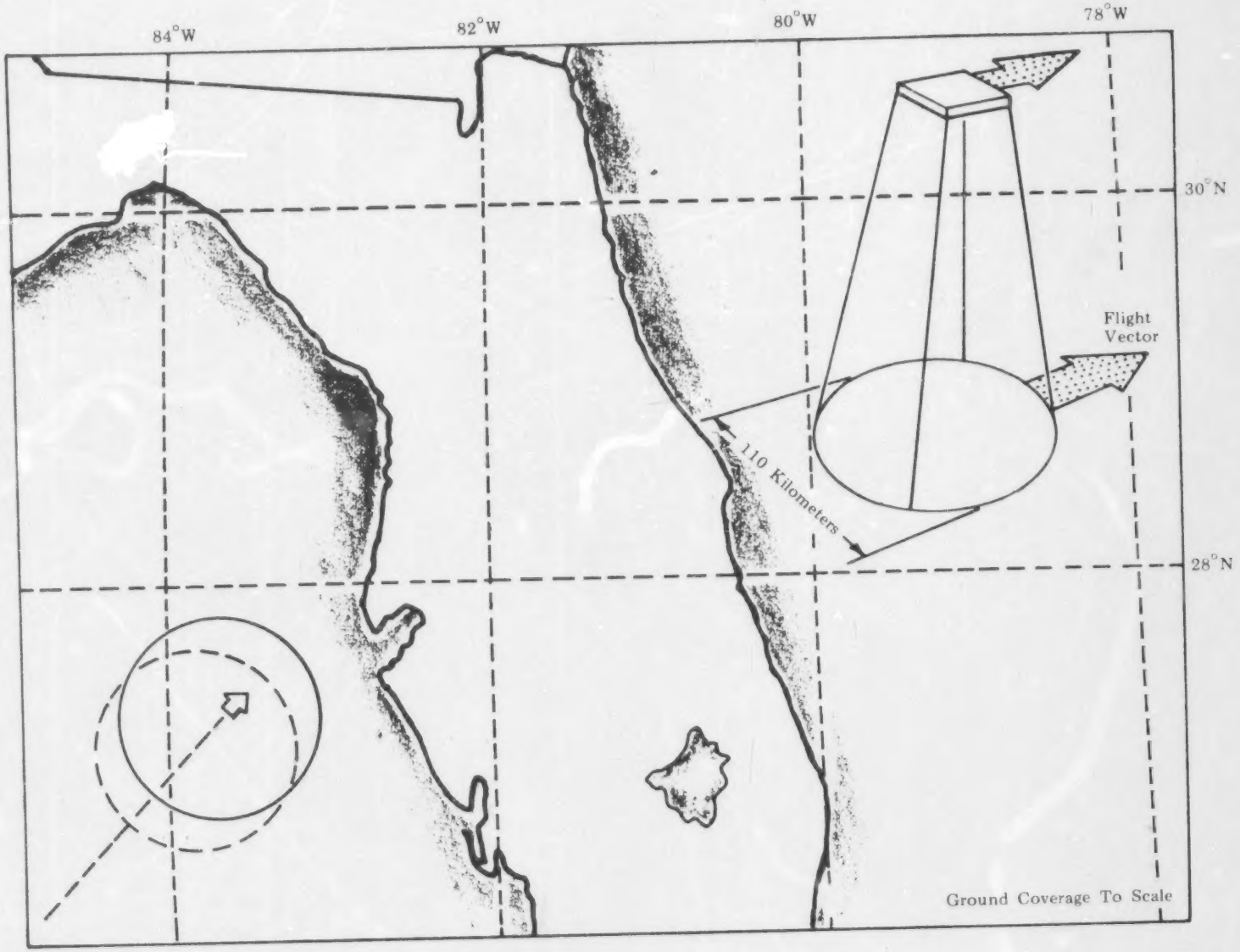


Figure 27 Ground Coverage of the S194 L-Band Radiometer

c) Plots of the centerline and approximate sidelines of the sensor field-of-view on a latitude-longitude grid with time annotations.

Tabulations

a) Radiometric antenna temperature including intermediate loss calculation factors.

b) Tabulations of raw data stream.

c) Sensor status data in engineering units.

d) Tabulation of sensor field-of-view, sun angle, and spacecraft attitude and position.

Section 7

Related Curriculum Activities

RELATED CURRICULUM TOPICS

The earth resource experimental sensors themselves present ideas for the teaching of many basic scientific concepts. The imagery data obtained from these sensors present yet another source of information to enhance and extend the teaching of a variety of scientific disciplines.

Because each of the sensors employs many of the same basic scientific concepts, the entire group of experiments will be treated together.

Biology

- Distribution of biomes.
- Absorption characteristics of chlorophyll.
- Relationship between water temperature, zooplankton, and schools of fish.
- Migration patterns of whales and fish.
- Pollution concentrations in relationship to technological development, urbanization and topographic characteristics.
- Binocular vision.

Chemistry

- Relationship between energy absorbed and the chemical nature of the material.
- The effects of atmospheric pollutants on the warming and cooling of the earth's surface.
- The variation in reflected and emitted microwave signal for materials of differing dielectric constant.
- Characteristics of infrared detectors (e.g., SiPbS, HgCdTe).

Earth Sciences

- Ground scales in imagery.
- Locating political boundaries.
- Topographical features.
- Distribution of soil types to climate.

- Distribution of resources with relation to political boundaries.
- Cartography.
- Wind patterns over oceans.
- Effect of large metropolitan areas with respect to heat output, atmospheric changes, etc.
- Effects of cloud cover on warming and cooling of the earth's surface.
- The effect of surface features on cloud formation.
- Vertical temperature gradient in relation to cloud formation.
- Effect of land use on microwave radiation (strip mines, lumbering, agriculture, reservoirs, etc.).
- Drainage patterns in relation to substrate topography.
- Land use studies.
- Ocean currents and migratory practices of whales and fish.
- Seasonal variation of icebergs and glaciers.
- Location of faults.
- Stresses upon agricultural crops.

Electronics

- Characteristics of detectors.
- Calibration of detectors.
- Spectrometers.
- Optical scanners.
- Microwave.
- Radar.
- Scatterometers.
- Radiometers.
- Antenna.

Mathematics

- Scale relationships in imagery.
- Trigonometry.
- Geometry.
- The use of units of measurements.

Photography

- The resolution of lenses.
- The relationship of wavelength to resolution.
- Reflection and refraction.
- Behavior of absorption filters.
- Use of telescopes and cameras.
- Characteristics of photographic emulsions.
- Cassegrain telescopes.

Physics

- The resolution of lenses.
- The relationship of wavelength to resolution.
- Reflection and refraction.
- Behavior of absorption filters.
- Characteristics of transparent, translucent, white and colored, as well as opaque materials.
- Telescopes and cameras.
- The electromagnetic spectrum.
- Sources of waves.
- Relationship of wavelength to energy.
- Refraction of waves.
- Polarization.
- Constructive and destructive interference.
- Sources of energy.

- Absorption and heating.
- Black body radiation.
- Particle and wave theory.
- Characteristics of electromagnetic radiation.
- Speed of light.
- Binocular vision (stereo photography).

Social Science

- Habitation concentrations in relation to natural resources, land area, natural transportation routes, etc. (i.e., optimum location for cities).
- Natural political boundaries.

SUGGESTED CLASSROOM DEMONSTRATIONS

Demonstration of Color Reconstruction by Addition and Subtraction

When red, green and blue light are projected together so that these impinge upon one another, the result is white light (or nearly so, because it depends upon the intensity of each light source as well as the spectral characteristics of the filters). These are the primary additive colors. Photograph a scene using color transparency film and the proper selection of red, green and blue filters. By making exposures through blue, green and red filters and also without a filter, one may obtain color positive transparencies for projection, including a control or reference. Using three projectors the three images may be superimposed upon one another. The registration of the three images is a technical problem which requires some care and attention. Compare the result to the transparency taken with color film and no filter. (Refer to Figure 28.)

These transparencies may also be prepared by using black and white film and the proper filter, then producing a black and white positive transparency of the negative. These can be projected or sandwiched with the appropriate filter.

If white light is projected through a red filter, the red light is transmitted and blue and part of the green is absorbed. If the remaining light is passed through a blue filter, the red light is absorbed. Thus, by passing white light through red, green and blue filters in any sequential order, all of the light will be absorbed. This is an example of color subtraction.

If one uses the colors which are opposite on the color triangle one has the subtractive primary colors. When the scene which

was photographed in the red band is dyed cyan, the green dyed magenta the blue dyed yellow; and these three images are superimposed, one will observe the natural color rendition. Remember that for this exercise you must first obtain the image taken in the desired spectral band, then dye the image (a black and white positive transparency may be sandwiched with a filter) the complementary color.

An alternate approach is to obtain black and white positive transparencies of multispectral bands. These may be copied by diazo or ozalid (Technifax, etc.) in the desired colors of blue, cyan, green, yellow, red, and magenta for color addition and subtraction demonstrations.

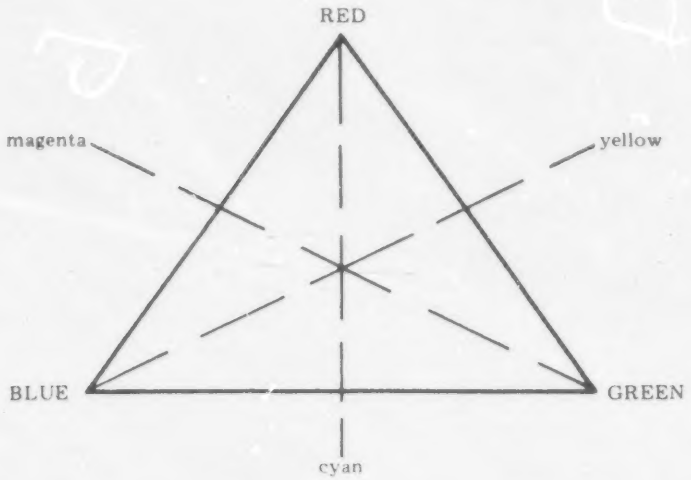


Figure 28 Colors in CAPITAL Letters are Primary Colors. Colors in Lower Case Letters are Complementary Colors.

False Color Infrared

False color infrared images combine the green, red and near infrared bands while omitting the blue (because the clouds and moisture scatter the blue light). To aid in the interpretation, the spectral images are colored. Relying upon three color projection, the images are dyed or projected through the color one step back on the color wheel. (Refer to Figure 29.) Thus the green band image is projected through blue, the red band through green and the infrared through red. This combination produces the "False Color Infrared." One may experiment with other combinations, such as using green for the infrared because of its relationship to healthy vegetation.

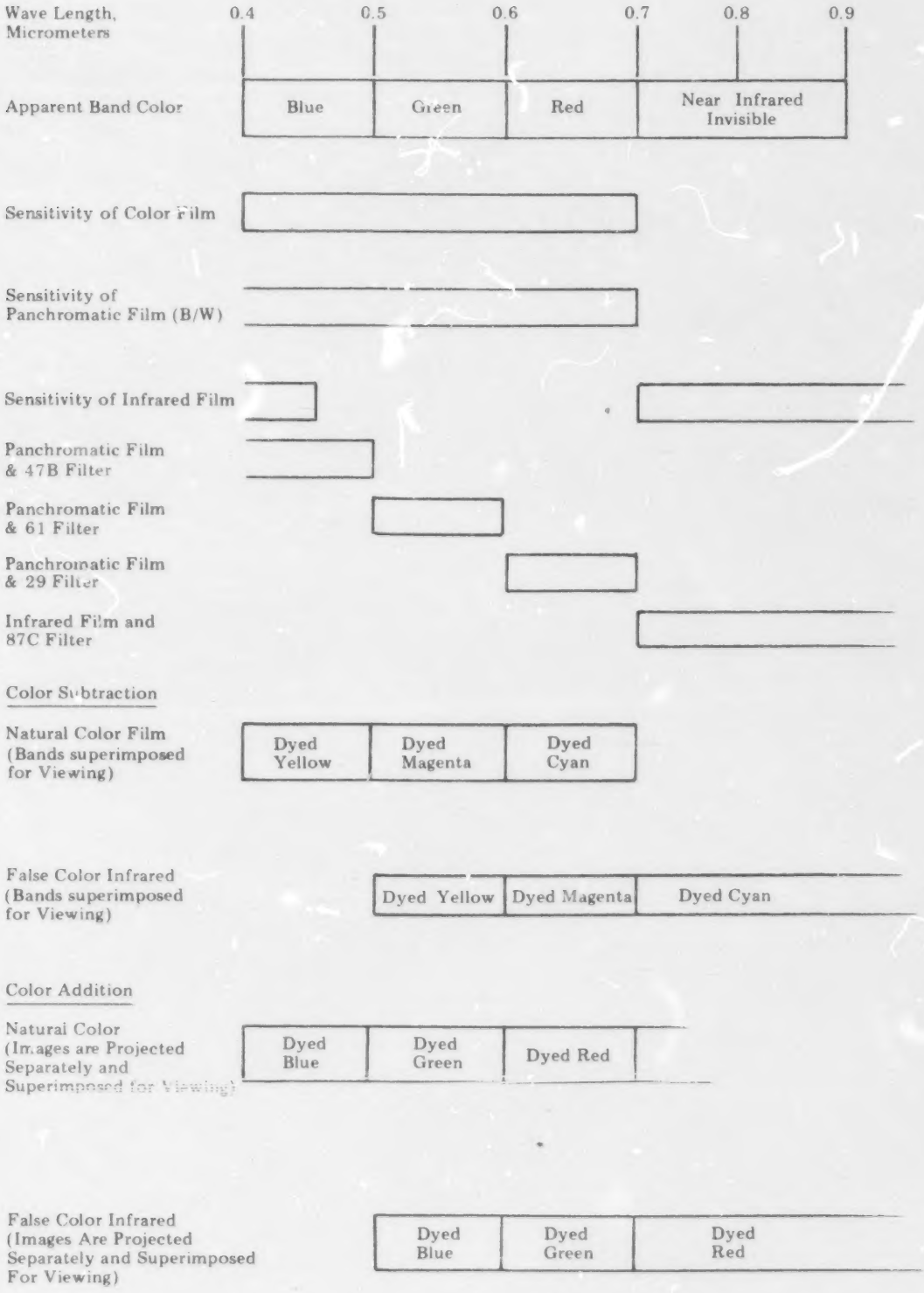


Figure 29 Characteristics of Films and Filters for Multispectral Photography

If one wishes to use color subtraction, the green band would be dyed yellow, the red dyed magenta and the infrared dyed cyan.

Selection of Filters for Multispectral Photography

In performing the color reconstruction and false color IR experiments described above one may rely upon the spectral transmission curves for standard photographic filters or one may determine these with a colorimeter such as a Bausch and Lomb Spectronic-20. Obtain the gelatin filters, cut strips of the filter material 10 mm wide to fit within the standard 13mm x 75mm test tubes or cuvettes. The light passes through the lower portion of the tube, so the filter material need only be about 20-25mm long and 11-12mm wide. These may be taped to thin cardstock strips for easy insertion and removal from the cuvette. The Spectronic 20 has an optional infrared bulb and filter to extend the response through the photographic infrared region. Filter materials obtainable from Edmund Scientific (Catalog Item Number 60,373) may also be tested.

After making the appropriate filter selection one may use panchromatic film and high speed infrared film to produce the desired spectral bands.

One may use a test plot and take the multispectral photographs from a ladder, or suitable elevated platform to obtain a vertical perspective of the scene being photographed.

Resolution

Resolution may be tested by determining the distance at which two objects are perceived as discrete rather than a single object. Place two black spots of identical size on a white card (or use Figure 30). The separation should be equal to their diameter. Also prepare similar cards with the spots in red and in blue. This exercise will yield the distance an individual can resolve the dots. Begin beyond the point at which the individual can distinguish the pattern as two dots. The person walks forward until he can resolve spots of given character a known distance apart. Repeat with red and blue. How do the distances for the red and blue compare? Can you make a statement relative to resolution and wavelength?

This exercise may be repeated with different linear shapes, etc., to show that resolution is a function not only of the system, but the wavelength, shape, orientation and contrast of the objects themselves.

Thermal Infrared

A simple infrared detector may be obtained from Edmund Scientific Co (Catalog item number 41,595), or other

scientific supply houses. This kit may be modified so that one may scan a given scene line by line and build up a thermal pattern or image.

An oil film may also be used to detect thermal infrared. The thermal energy will vaporize the oil leaving a pattern which may be viewed with a low angle side illumination. Coat a plate with a thin film of oil, then place in a box with a pin hole (this "pinhole camera" may be used as a crude thermal imager as the pinhole will allow the passage of thermal infrared whereas a glass lens would absorb it). After exposure (by trial and error), the plate may be removed and viewed by low incident light. This image may be photographed if it is to be retained for study. The nature of the oil used, length of exposure, size of pinhole and the thermal emissions provide sufficient variables for an open ended project.

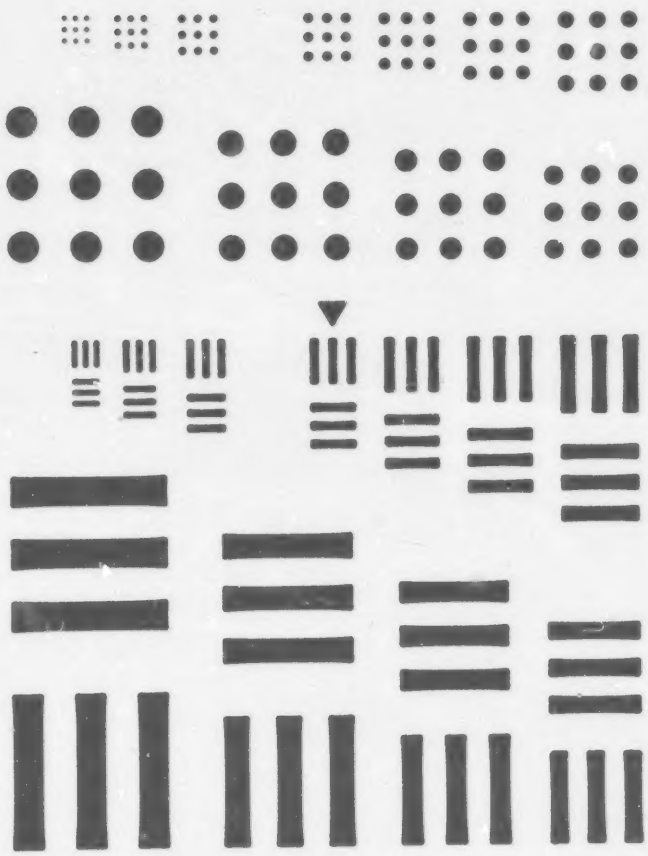


Figure 30 Bar and Dot Resolution Chart

Spacecraft Photographic Interpretation

Obtain ERTS and EREP photographs containing your local area. Compare the geography with an oil company road map and geological survey maps. What statement can you make when comparing discernible geological features between the spacecraft photographs and the maps, concerning the accuracy of the road and survey maps?

Section 8

Appendices

APPENDIX A
REMOTE SENSOR DISCUSSION

GENERAL

All remote sensors consist of the four basic types of components shown in Figure 31. Collectors may be lenses, mirrors, or antennas; detectors are films, photoconductor diodes, or resonant cavities; typical signal processors are load resistors and amplifiers; and outputs may consist of photographs, strip charts, magnetic tape recordings, and spectrographs. The components function differently in each class of sensor and these differences may be used advantageously to obtain the information required to sense various resources.

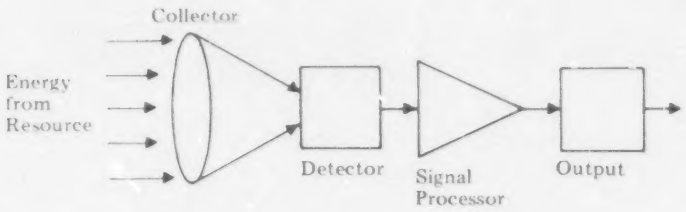


Figure 31 Basic Components of a Remote Sensing Instrument

CAMERAS

The camera provides high resolution, ready availability, and highly developed data analysis techniques. Cameras operate at the short visible wavelengths to produce an image, or picture, of the resource area that can be interpreted readily by the eye. The collector is a glass lens, but the other components vary with the type of camera. All elements of the scene are recorded simultaneously, so in a given image there is good registration and constant illumination.

Most photographic sensors record reflected sunlight on film that varies in size from about two to ten inches depending upon the photoscale desired. Film, an excellent recording medium, is inexpensive, rugged, has wide dynamic range, and can cover the spectrum from the ultraviolet through the near infrared. The longest wavelength in the infrared that film can record is about 1.1 micrometers. This limit is due to the decrease in the number of photons emitted by the sun in the infrared, and to the lack of sufficient energy in the individual photon to cause the chemical action that forms the image on the film. The practical limit on the ultraviolet side of the visible spectrum is set by the camera lens which absorbs the ultraviolet before it can reach the film, and by the atmospheric ozone that absorbs the ultraviolet sunlight both as it enters and leaves the atmosphere. The same general reasoning applies to a television camera that uses a photocathode

instead of film. The spectral range of television is narrower than film, as in the case of the Earth Resources Technology Satellite return beam vidicon camera, where it is 0.457 to 0.830 micrometers.

Multispectral Camera

The multispectral camera is used when it is necessary to discriminate areas that have slightly different spectral reflectance characteristics. The difference are too subtle to show on the broadband color film used in metric cameras, but they can be detected by comparing (through color manipulation or enhancement), a number of photographs each taken in a narrow band. Being cameras, the light sensed is reflected sunlight.

DISCRIMINATE— As used here, the term "discriminate" denotes the successive classification of larger classes into smaller more precisely defined subclasses. The crudest phase of discrimination is the simple recognition that different materials are, indeed, different.

The multispectral camera typically does not have as large a field of view nor as precise definition as a metric camera, but since all photographs are taken simultaneously, rather than in several sequential passes (as would be necessary with a single metric camera), the image-to-image registration is better and the illumination on each photo is the same.

RADIOMETERS

A radiometer sensor consists of the same elements as a camera, however, their function is different. A camera senses reflected sunlight and forms an image of the scene, while a radiometer senses energy re-radiated (emitted) by the surface and usually does not form an image of the scene. All substances at temperatures above absolute zero radiate energy with intensity directly dependent upon its temperature, and it is this re-radiated energy that radiometers sense. (Radiometers that sense reflected energy are called reflectometers or polarimeters). The radiometer collects all the radiation from a single element on the surface. At microwave wavelengths, these elements tend to be large. As the spacecraft moves, the radiometer observes a swath along the ground track.

Microwave Radiometer

A microwave radiometer is characterized by a large antenna (energy collector) necessitated by the relatively long wavelenths of microwave energy. The surface emitted energy is often collected by a paraboloid reflector, and it is measured by comparing it in ermittently to a calibrated reference load. The amplitude of the incoming signal is proportional to the temperature of the emitting surface. Radiometers are especially attractive if particularly high spatial resolution data is not needed, but it is necessary that the experiment see through weather.

Radiometers actually measure the product of the emissivity and the absolute temperature of the emitting surface (often called the brightness temperature). Thus, the brightness temperature of a surface of uniform molecular temperature will vary if the emissivity varies. Throughout the microwave range, there are certain frequency bands where the emissivity is more sensitive to the roughness of the surface, and at those frequencies a radiometer can be used to measure surface roughness, such as sea state. In those frequency bands where roughness has less effect on the emissivity, the brightness temperature is a measure of the actual surface temperature and a radiometer can be used to measure it.

EMISSIVITY— The ratio of the radiation emitted by a material to the radiation emitted by a BLACK BODY at the same temperature and under similar conditions. Excepting for luminescent materials, the emissivity ratio can never be greater than unit.

At longer microwave wavelengths, the polarization phenomena becomes more easily measurable, and scientists have found that sensing the horizontal and vertical polarized radiation from the surface separately improves test results.

SCANNERS

A scanner is a camera, or a radiometer sensor, whose collector oscillates back and forth across the ground track while forward scanning is provided by the forward motion of the spacecraft. All scanners are imagers, and an infrared scanner can produce a picture that rivals the clarity of a film camera. Scanners are used where one needs a large total field of view and high ground resolution, but cannot carry a collector as large as the objective lenses of the metric camera to take in the whole scene.

Infrared Scanner

The infrared scanner is used widely in remote sensing and usually can sense simultaneously in several reflective infrared channels. One of three collector designs usually are used with the infrared scanner. One rotates a faceted mirror around an axis parallel to the flight path. The incoming beam is reflected by one of the facets into an optical train that focuses it onto the detectors. Spectral selection is achieved by combinations of filters and detectors that are matched to each wavelength desired.

The collected energy is focused on a semiconductor and changes its electrical properties (e.g., conductivity) proportionally to the average temperature of the scene being viewed. The photoconductive detectors are more sensitive and have a better signal-to-noise ratio if they are refrigerated. Cooling by radiation to space can achieve detector temperatures of about two hundred degrees Kelvin. A liquid nitrogen cooler (cryogenic cooler) can maintain about seventy-seven degrees Kelvin, and an improvement of up to 10 to 1 may be expected with liquid helium refrigeration to near thirteen degrees Kelvin.

The Earth Resources Technology Satellite infrared scanner uses a flat mirror collector that scans the surface by oscillating back and forth across the flight path. The Skylab Multispectral Scanner rotates a small flat mirror that scans successive continuous lines across the flight path in a conical line scan.

The Skylab Multispectral Scanner senses reflected visible and infrared sunlight, but with much higher spectral resolution than a camera loaded with film. Its pictures are particularly effective in detecting resources whose absorptivity and reflectivity are different from its surroundings (e.g., the reflection of sunlight by chlorophyll in a healthy plant and the lack of reflection from a diseased plant). A long wavelength (thermal) infrared channel that detects the energy emitted by the surface is added, so an image of the scene can be made both from reflected and self-emitted energy. Also, the thermal infrared channel can be used at night.

REFLECTIVITY— The fraction of the incident radiant energy reflected by a material that is exposed to uniform radiation from a source that fills its field of view.

SPECTROMETERS

Spectrometers measure the wavelength of the electromagnetic energy that is reflected, absorbed, and emitted from substances, rather than their shape (as measured with a camera). Like a radiometer, the spectrometer is a passive device that collects all of the reflected or emitted energy from a single element on the surface and yields a spectrogram instead of an image along the flightpath. However, the spectrometer collector contains a device (e.g., a filter wheel, prism, or grating in an optical spectrometer) that passes to the detector only selected narrow bands of the total spectrum. The spectral resolution of the spectrometer is far greater than the multiband camera, or the multichannel radiometer. The relative amount of energy in these narrow bands indicates the nature of the surface that reflected or emitted the energy, or the atmosphere through which the energy passed prior to collection.

Infrared Spectrometer

The Infrared Spectrometer provides a measurement of the temperature and water vapor profiles of the atmosphere. It makes a spectral analysis of the radiation in bands covering the visible through near infrared (i.e., 0.4 to 2.5 micrometers) and in the thermal infrared bands (i.e., 6.6 to 16.0 micrometers). A mirror is used as a collector, and incoming radiation may be passed through a spectrometer entrance slot and split into spectral bands by a dichroic beam splitter. Some spectrometers use a circularly-variable interference filter wheel as the bandpass isolation element. Visible and near-infrared energy is detected by a mercury-cadmium-telluride detector cooled to 90°K by a cryogenic cooler.

RADARS

Radar is an active microwave device that supplies its own scene illumination instead of relying upon radiant emission or reflected sunlight. Radar requires a transmitter as well as a receiver and consumes relatively large amounts of power, but it is capable of high spatial resolution.

The transmitted signal is directed toward the target by an antenna that serves as a collector as well as a transmitter. The interval between the transmission of the pulse and its reflected return is a measure of distance to the various objects in the scene, and the antenna angle gives the angular position of the objects with respect to the satellite ground track. The strength of the reflected signal indicates the shape of the object; a smooth road, an angular building, or a power line tower all reflect signals at different intensities. The radar has a small ground resolution element size and generates data readily handled by direct readout.

Scatterometer

If the resource of interest is large sized and can be recognized by its roughness, a form of microwave radar called a scatterometer may be required. When operating at wavelengths shorter than about one meter (300 MHz), the scatterometer measures the amount of backscatter from the surface roughness in broad categories ranging from smooth to very rough. It may also be used to measure sea surface roughness. Refer to Figure 32. At frequencies of about 200 MHz, the reflectivity depends upon dielectric constant; at lower frequencies, reflectivity depends primarily upon electrical conductivity. These lower frequencies penetrate the surface and map subsurface structure. The scatterometer operates at microwave frequencies so the ground resolution element tends to be very large (miles in extent) for a reasonably sized antenna.

The polarization of the radar signal affects the image by emphasizing those terrain features that have favorable orientation with respect to the antenna. With one antenna it is possible to get four different sets of signal polarization; horizontal (H) or vertical (V) transmission and horizontal or vertical reception. Combinations of these transmitted and received polarizations may also be useful (i.e., HH, HV, VV, and VH for transmitted and received signals, respectively).

The microwave radar has excellent cloud and precipitation penetration. Radar imagery commonly is taken through 3,048 meters (10,000 feet) of clouds with no apparent degradation of the data. However, because of the smaller area coverage of radar, it has a clear advantage over photography only when cloud cover significantly inhibits photography.

The radiated microwave radiation may also penetrate foliage to provide an image of underlying solid surface. This makes radar particularly valuable for studying geologic surface structures, such as faults, lineaments, and rifts.

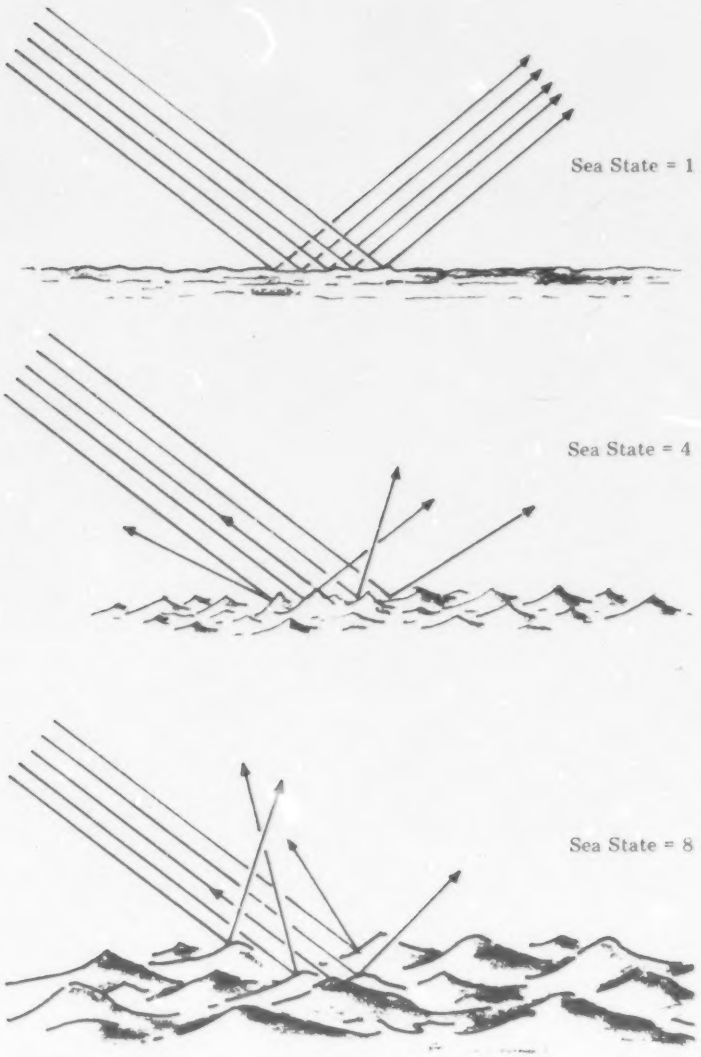


Figure 32 Illustration of Microwave Radar Backscattering

A. From a smooth ocean surface (Beaufort Sea State #1).
B. From a moderately rough ocean surface (Beaufort Sea State #4).
C. From a rough sea surface (Beaufort Sea State #8).

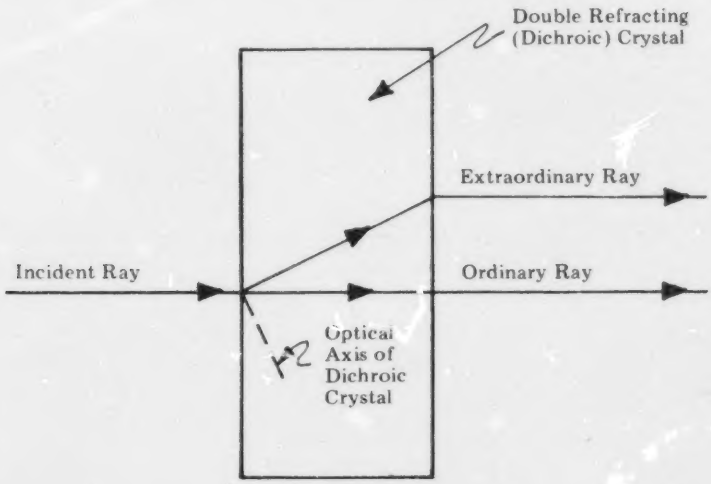
APPENDIX B
GLOSSARY

Term	*Definition*
Biome	A complex biotic community covering a large geographic area (such as tundra, desert, coral reef, woodland, etc.) and characterized by the distinctive life forms of important climax species of plants and animals.
Biosphere	The life zone of the earth (i.e., the part inhabited by living organisms.)
Black Body	A term used to denote an ideal body which would, if it existed, absorb all and reflect none of the radiation falling upon it: its reflectivity would by zero and its absorbtivity would be 100%. The primary interest attached to such a body lies in the character of the radiation emitted by it when heated and the laws which govern the relations of the flux density and the spectral energy distribution of that radiation with varying temperature. (Refer to the STEFAN-BOLTZMANN law, and PLANCK'S EQUATION in a Physics textbook.) Scientists can construct equipment approaching the ideal black body (i.e., the radiation from this equipment when heated resembles the ideal black body radiation), and this approach usually employs an elongated, hollow metal cylinder, blackened inside, and completely closed, except for a narrow slit in the end from which radiation escapes when the cylinder is heated.
Brightness Temperature	The effective object temperature, T_T, which evolves from the following radiation concepts. The radiation emanating from an object is, in general, made up of three parts: a self-emitted component, a reflected component, and a transmitted component. The self-emitted component, for instance, is proportional to the object's spectral emittance ϵ_λ and its temperature T_o. Thus, an effective temperature (T_{Te}) due to self-emission can be defined as the product of the object temperature and its emittance; i.e., $$T_{Te} = \epsilon_\lambda T_o$$ Similarly, effective temperature contributions (T_{Tr} and $T_{T\tau}$) due to the object's spectral reflectance (ρ_λ) and transmittance (τ_λ) can be written in the forms $T_{Tr} = \rho_\lambda T_i$ and $T_{T\tau} = T_\lambda T_i'$ where T_i and T_i' are terms proportional to the radiation incident on the object. The effective object temperature T_T is thus the sum of these three terms; i.e., $$T_T = \epsilon_\lambda T_o + \rho_\lambda T_i + \tau_\lambda T_i'$$ This is the temperature of the object as one would measure it with a remote microwave sensor having an ideal antenna. It would be the same as the object's actual temperature only if the object were a black body, in which case $\rho_\lambda = \tau_\lambda = 0$ and $\epsilon_\lambda = 1$. Thus for real objects, the remotely observed radiation intensity is dependent not only on the object temperature and the incident radiation, but also on several other properties of

the object. The emittance, reflectance, and transmittance are, in general, functions of the object material's absorption coefficient, its bulk configuration or shape, the aspect at which the object is viewed, and the surface structure.

Dichroic

Certain double refracting crystals (such as Calcite) which exhibit the property of breaking (beam splitting) a ray incident normally to its surface into two rays in traversing the crystal. The normal transmitted ray is known as the ORDINARY RAY and the deviated ray is the EXTRAORDINARY RAY, as shown in the accompanying illustration.



Dielectric Constant

For a given dielectric material, the ratio of electrical capacitance of a dielectric-filled capacitor to a vacuum capacitor of identical dimensions.

$$K = \frac{C}{C_o}$$

C = capacitance of dielectric
C_o = capacitance of the empty capacitor

Dielectrics

Materials which are electrical insulators. In a more general sense, dielectrics include all materials except condensed states of metals (i.e., conductors). A dielectric is a substance through which an electric attraction or repulsion (electric field) may be sustained.

Diffraction

For the visible spectrum, the breaking up of a ray of light into dark and light bands, as when deflected at the edge of an opaque object. In general, it is the breaking up of electromagnetic waves into component parts of their spectrum.

Discriminate

As used here, the term "discriminate" denotes the successive classification of larger classes into smaller more precisely defined subclasses. The crudest phase of discrimination is the simple recognition that different materials are, indeed, different.

Emissivity

The ratio of the radiation emitted by a material to the radiation emitted by a BLACK BODY at the same temperature and under similar conditions. Excepting for luminescent materials, the emissivity ratio can never be greater than unity.

Emittance

The radiant emittance of a source is the power radiated per unit area of surface.

Electromagentic Radiation

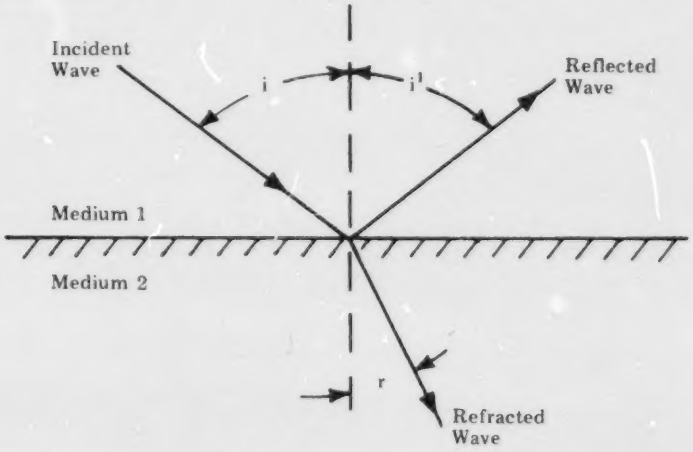
Energy transmitted through space or through a material medium in the form of electromagnetic waves. The term can also refer to the emission and propagation of such energy. Whenever an electric charge oscillates or is accelerated, a disturbance characterized by the existence of electric and magnetic fields propagates outward from it. This disturbance is called an electromagnetic wave. The frequency range of such waves is tremendous and is known as the ELECTROMAGNETIC SPECTRUM. All electromagnetic waves travel with the velocity of light.

Evapotranspiration

The combined processes of evaporation of liquid or solid water plus transpiration from plants.

Incident Wave

Whenever electromagnetic wave trains, traveling in one transparent medium, strike the surface of a second transparent medium whose index differs from that of the first (that is, in which the velocity differs from that in the first), two new wave trains are found to originate at the interface. One, the *reflected* wave, travels back into the original medium, while the other, called the *refracted* wave, is propagated into the second medium. The accompanying diagram illustrates this phenomena.



For Reflection: $i = i'$

For Refraction: $\frac{\sin i}{\sin r} = \left[\frac{\epsilon_2}{\epsilon_1}\right]^{1/2} = N$

Where ϵ_1 and ϵ_2 are the dielectric constants of mediums 1 and 2, and N is the INDEX OF REFRACTION.

Polarization

A distinct orientation of the wave motion and travel of electromagnetic radiation. Discrimination techniques use differing and perhaps characteristics amounts of polarization introduced by materials in the radiation reflected or emitted to distinguish material categories.

Reflection

A change of direction of propagation of any wave phenomenon which occurs when the incident wave is deflected back into the original medium. Refer to Incident Wave.

Reflectivity

The fraction of the incident radiant energy reflected by a material that is exposed to uniform radiation from a source that fills its field of view.

Refraction

A change of direction of propagation of any wave phenomenon which occurs when the wave velocity changes due to wave propagation into a different medium. Refer to Incident Wave.

Spatial

The distribution of electromagnetic radiation as related to the location, shape and texture of sensed phenomena.

Spectral

The distribution of electromagnetic radiation as a function of wavelength. In the visible range, variations are noted by changes in color.

Spectral Signature

Spectral reflectivity and emissivity characteristics of objects observed. Spectral signatures are not completely deterministic, i.e., spectral signatures are statistical in character with some mean and some dispersion around it for a particular observed phenomena.

When electromagnetic radiation strikes the boundary of solid matter, a number of interactions are possible. Mass and energy are conserved according to basic physical principles, and energy can either be:

1. TRANSMITTED — propagated through the solid matter.

2. REFLECTED — returned unchanged to the original medium.

3. ABSORBED — giving up its energy largely into heating the solid matter.

4. EMITTED — or more commonly, re-emitted, by the matter as a function of temperature and structure, at the same or different wavelength, or

5. SCATTERED — deflected to one side and lost ultimately to absorption or further scattering.

Therefore, TRANSMISSION, REFLECTION, ABSORPTION, EMISSION, and SCATTERING of electromagnetic energy by

any particular type of matter are selective with regard to wavelength and are specific for that particular type of matter, depending primarily upon its atomic and molecular structure. Thus, in principle, it is possible to identify the material of a remotely sensed object from either a wavelength plot, or any other record which is sufficiently detailed to show its spectral TRANSMISSION, REFLECTANCE, ABSORPTION, EMISSION and/or SCATTERING properties.

Transmittance

The ratio of electromagnetic radiation intensity, or radiant power, I_O, incident upon a material; to the intensity of the power, I, transmitted by the material. Thus transmittance, $T = I/I_O$.

Transpiration

The portion of water absorbed by plants that escapes from them as water vapor.

Units

The following unit abbreviations are used in this volume:

PREFIX	*ABBREVIATION*	*MULTIPLIER*
giga	G	10^9
mega	M	10^6
kilo	K	10^3
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

APPENDIX C
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